ARMY RESEARCH LABORATORY

Multimodal Guidance for Land Navigation

**by Linda R. Elliott, Maaike Duistermaat,
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Army Research Laboratory

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14. ABSTRACT

This report describes the third in a series of collaborative experiments between the U.S. Army Research Laboratory and TNO Human Factors (Soesterberg, The Netherlands). In each experiment, a personal tactile navigation (PTN) system for land navigation was compared with alternate land navigation systems in wooded terrain at Fort Benning, Georgia, during high-workload conditions that included secondary tasks such as radio communications, target detection, and determination of location coordinates.

This report briefly summarizes results of the first and second studies and describes in further detail the third experiment which assessed navigation and target detection performance when the PTN and a hand-held commercial global positioning system (GPS) device were used singly and together. Most important are findings relevant to how systems can be used most effectively when Soldiers have both. Results demonstrate the effectiveness and high Soldier appreciation of having both systems. This report also contains Soldier recommendations for how both systems can be improved and how best to use both systems when in operations.

15. SUBJECT TERMS

Army performance; IMPRINT workload analyses; land navigation; multimodal display; multiple resource theory; Soldier performance; tactile display

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1. Background

Current and future Army command and control (C2) systems include advanced communication systems that will enable information creation and distribution to extraordinary levels. While research and technology address issues of information requirements, distribution, and decision support, there remains the challenge of information overload and information display. How can future informa-tion displays be designed to aid information perception, interpretation, and mission performance? Battlefield situation awareness (SA) (i.e., knowledge of location) is more than the effective distri-bution of information; human interpretation and decision making will always be critical.

The U.S. Army Research Laboratory (ARL) initiated an advanced science and technology objec-tive (ATO) that would develop information system interface solutions to reduce cognitive work-load, enhance SA, shorten decision-making times, and improve decision accuracy. Experimental approaches have been developed, based on identification of operational task demands, ratings of task workload (visual, audio, cognitive, speech, physical), and theory-based predictions, drawn from Multiple Resource Theory (MRT) (Wickens, 2002). The objective of this ATO is to apply multi- and uni-modal interventions to task situations typified by high and conflicting workload.

This report describes the third in a series of collaborative experiments between ARL and TNO[1] Human Factors (Soesterberg, The Netherlands). In each experiment, a personal tactile navigation (PTN) system for land navigation was compared with alternate land navigation systems in wooded terrain at Fort Benning, Georgia, during high-workload conditions including secondary tasks such as radio communications, target detection, and determination of location coordinates. In the first experiment (Elliott, Redden, Pettitt, Carstens, van Erp, & Duistermaat, 2006), the PTN was com-pared with the traditional Army compass system and the current hand-held Army global position-ing system (GPS): the precision lightweight precision GPS receiver (PLGR). This first experi-ment was conducted during daytime conditions. The second experiment compared the PTN with the PLGR and the Army Land Warrior (LW) helmet-mounted navigation device during night conditions (Duistermaat, 2005). This report briefly summarizes results of the first and second study and describes in further detail the third experiment, which assessed navigation and target detection performance when the PTN and a hand-held commercial GPS device (the Garmin) were used, singly and in combination.

The rationale for these studies was based on principles drawn from the MRT and on IMPRINT (Improved Performance Research Integration Tool) task and workload analyses. IMPRINT analyses explicate tasks and their interdependencies so that they can be modeled. Each task is

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[1]Nederlandse Organisatie voor Toegepast-Natuurwetenschappelijk Onderzoek / Netherlands Organisation for Applied Scientific Research.

rated for workload (visual, audio, cognitive, psychomotor) consistent with MRT (Keller, 2002). IMPRINT analyses of Future Force Soldier roles predicted critical mission roles and situations associated with particularly high visual workload (Mitchell, Samms, Glumm, Krausman, Brelsford, & Garrett, 2004). One of these situations was that of the dismounted Soldier performing land navigation in a combat scenario. As a result, the PTN system was identified as a means to reduce attentional demand and workload associated with land navigation by dismounted Soldiers.

1.1 Multiple Resource Theory

IMPRINT task and workload analyses identified land navigation by the dismounted Soldier as a task typified by high visual and cognitive workload, particularly in the context of combat missions (Mitchell et al., 2004). Much of the workload for land navigation depends on ambient and focal visual information processing, which, according to MRT, can be reduced by off loading to a different sensory channel (Boles, 2001; Wickens, 2002). Simply stated, MRT proposes that (a) people have several independent capacities with resource properties; (b) some resources can more easily be used in tandem, while other combinations are more difficult and would be performed more sequentially; (c) tasks using compatible resources can usually be performed together; and (d) competition for the same sensory modality can produce interference. MRT defines these capacities and contingencies (Wickens, 2002).

More specific hypotheses can be drawn regarding the degree of task interference, based on the extent that the tasks share stages, sensory modalities, codes, and modes of visual information processing (i.e., focal versus ambient) (Wickens, 2002). "Processing stages" distinguish the more deliberative cognitive resources required by perception and cognition versus the more easily automated resources required in selecting and executing responses. Wickens also makes a distinction between spatial and verbal processes, stating that two tasks compete for resources when they are similar in resource demand. He also noted that manual responses are often spatial and automated in nature (e.g., walking) and can often be performed effectively when combined with a verbal task (e.g., talking on a radio). When tasks are complementary, there will be less competition for resources, more efficient time sharing, and changes in the difficulty in one task will not have a large effect on the performance of the other task.

Given the high visual and decision-making workload indices generated by IMPRINT task analyses (Mitchell et al., 2004) of dismounted land navigation, we decided that the PTN system had potential to reduce workload and enhance performance. First, the cognitive resources required by a well-designed torso-mounted tactile system would be simpler and more intuitive in response. The PTN tactile belt is composed of an adjustable belt with 8 "tactors" (see figure 1). When the tactor is activated, it vibrates in a manner similar to a pager or cell phone (in vibrate mode). With the PTN tactile belt, the tactor that is activated indicates the direction of the next waypoint. The Soldier simply turns in the direction of the activated tactor, until the tactor in front (e.g., nearest his navel) is activated. When the front tactor is activated, the Soldier simply walks straight ahead in order to reach the waypoint. If s/he veers off course to the left or right, the corresponding tactor

will be activated to steer the Soldier back on course. In addition, the perceptual modality used for information presentation is tactile and should interfere less with the auditory or visual information channels (Wickens, 2002).

Figure 1. PTN, a torso-based tactile land navigation system. (Left: Soldier wearing PTN using a back-pack to hold the system equipment. Top right: the tactile display [waist belt] with the tactors. Bottom right: the PTN system equipment [break-out box, microprocessor, sensor unit, battery unit].)

1.2   Some Previous Applications of Tactile Directional Cues

During the previous 20 years, basic research has been performed with regard to principles of vibrotactile perception relating to display design (Van Erp & Vogels, 1998). Many studies have also demonstrated the usefulness of tactile display in multitasking situations (Sarter, 2001, 2002) and in military operations (van Erp, 2005; van Erp, Groen, Bos, & van Veen, 2006). Tactile systems have proved particularly effective when other information channels are overloaded or distorted (e.g., auditory channel in a noisy environment; visual channel when visibility is low). For example, there has been particular investment and investigation of tactile applications for aircraft and helicopter pilot performance, resulting in many demonstrations of effectiveness for aircraft landing and hover tasks. Raj and his colleagues (1998, 2000; Rupert, 2000a, 2000b) reported the development and demonstration of a Tactile SA System (TSAS) for pilots, which provides three-dimensional (3-D) information to the air crew regarding orientation, velocity, and range. Experiments proved the effectiveness of the TSAS in actual flight tests (Chiasson, McGrath, & Rupert, 2003; McGrath, Estrada, Braithwaite, Raj, & Rupert, 2004). The tactile feedback helps to resolve some of the illusions that result in pilot spatial disorientation and counters ambiguities associated with 3-D audio feedback systems. According to Doll (1986), there is a zone of confusion for 3-D audio cues extending in front of the subject, so that estimations of elevation and azimuth show significant errors across a wide range of frequencies. The reversal errors from the zone of confusion have been demonstrated to be consistent and significant (Nelson et al., 1998). Van Erp, Veltman, Van Veen, & Oving (2003) demonstrated the effectiveness of the tactile vest concept in helicopter hovering tasks, where the tactile vest effectively provided altitude cue information to helicopter pilots, in situations of degraded visibility (i.e., night operations with night vision devices). Similarly, Van Erp (2005) reported successful application of tactile feedback for orientation of astronauts on board the international space station (Rochlis & Newman, 2000).

Recently, Aretz, Andre, Self, and Brenaman (2006) reported the application of the tactile vest concept to provide tactile feedback to UAV (unmanned aerial vehicle) pilots while they were landing. In a within-subjects comparison of UAV simulation performance with and without the vest, they found that the vest helped UAV pilots to more accurately perform a landing. The current Predator UAV ground control station includes a monitor with a map display and a second monitor that combines a forward camera view and a head-up display (HUD). Ground operators do not get the auditory, vestibular, and proprioceptive feedback that would be available to pilots in the cockpit. The tactile vest was developed to provide altitude deviation feedback through rows of tactors. If the operator was within 10 feet of the glide scope (i.e., correct corridor for movement), the vest was silent. If the operator was between 10 and 20 feet, the middle row of tactors vibrated at 100 ms on, 600 ms off. If the operator was greater than 20 feet above or below the desired glide slope, another row of tactors vibrated at greater intensity and frequency. Subjects using the vest learned the landing task with fewer trials and greater accuracy.

Tactile systems have also been developed and demonstrated effective for navigation situations. Dobbins and Samways (2002) used one tactor (i.e., a vibrotactile display element) on each wrist to effectively display a virtual corridor in a maritime navigation setting. Maritime navigation often occurs in situations of poor visibility (e.g., night operations, fog, etc.) and high craft motion (e.g., high levels of shock and vibration). The Navigation Tactile Interface System (NTIS) was demonstrated to aid navigation at speeds as fast as 70 knots and was used for the establishment of the blind world water speed record. The NTIS constructs a virtual corridor from one waypoint to the next. Waypoint location and corridor width are pre-programmed. Tactors were programmed to provide cues regarding whether the navigator should veer left or right in order to stay on course. It was determined that the tactile system was a viable alternative and an effective augment to visual display and was effective, regardless of high vibrations from the high-speed power boats. Dobbins and Samways (2002) also reported application of the TSAS, integrated with the Swimmer In-shore Navigation System (SINS) to aid diver navigation. The divers navigated a triangular course in good visibility, using visual or tactile cues. Both types of cues were effective; however, divers expressed preference for the tactile system. In another demonstration of tactile cues for navigation, Van Erp and van Veen (2004) demonstrated that tactors in a driver's seat can be used to successfully navigate a car through town. Direction and distance information was coded with the use of tactors in the car seat of a driving simulation. Participants drove different routes through a simulated city, with navigation information provided by visual cues, tactile cues, or both. Results showed better performance and lower workload with the tactile display.

Navigation cues are essentially cues of direction. The same concept of direction cues can apply to support targeting tasks. Effectiveness of tactile displays for direction cueing was recently reported by Carlander and Eriksson (2006) reporting high levels of effectiveness of tactile cueing for target direction feedback of threat direction to the drivers of the Swedish combat vehicle 90. Drivers were presented with 3-D audio cues, tactile vibration onto the torso, or both in combination, for threat cueing. Ten male combat vehicle 90 drivers from the Swedish Army combat school were told to turn the vehicle toward the threat as quickly and accurately as possible. Each driver handled 45 threats in total. Each of five threat directions was presented three times for each of the three threat cueing conditions. The results showed that the 3-D audio generated greater localization errors and reaction times with threats straight behind the vehicle/driver compared with the tactile and 3-D–tactile combination.

For information regarding direction cues for personnel outside a vehicle, Van Erp, Spapé, and Van Veen (2003) showed that a localized vibration on a waist belt, the PTN, could easily and accurately be used to provide direction cues. In this situation, it is intuitive to infer direction from the torso, which is relatively stable.

Because of the success of an initial demonstration for land navigation, ARL collaborated with TNO Human Factors to investigate effectiveness of the PTN in (a) more challenging terrain with longer routes, (b) day and night operations, (c) conjunction with secondary tasks, and (d) comparison with other land navigation devices.

2. Previous Collaborative Experiments

2.1 Day Operations

The first collaboration between ARL and TNO was conducted to assess PTN effectiveness for dismounted infantry land navigation and to compare performance using PTN for two existing Army land navigation devices (Elliott et al., 2006). Fifteen infantry Soldiers navigated three different routes of equal length (e.g., 600 meters) and terrain features. Each navigation route, composed of three waypoints, was traversed by each Soldier, each time with a different navigation device: (a) the traditional military compass system (see figure 2), (b) the PLGR hand-held GPS system (see figure 3), and (c) the PTN (see figure 1).
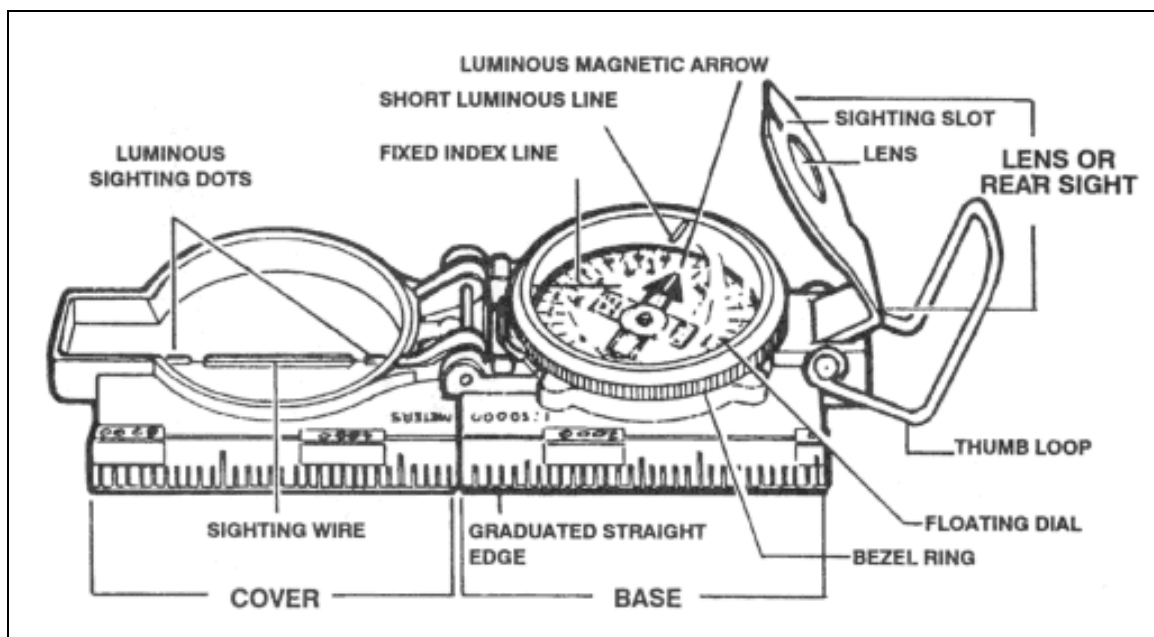
Figure 2. Army land navigation lensatic compass.

Table 1 describes the manner in which Soldiers were given direction and distance cues. When Soldiers were farther than 50 meters, the tactor most closely corresponding with the direction of the waypoint was activated, with a 200-ms buzz every second. If the waypoint is straight ahead, the tactor in front (above the navel) would be activated, with a 200-ms buzz every 2 seconds. When the Soldier approaches the waypoint (between 50 and 15 meters away), the tactor signal changes from a single buzz to a double buzz. When the Soldier arrives within 15 meters, all tactors are activated for 3 seconds.
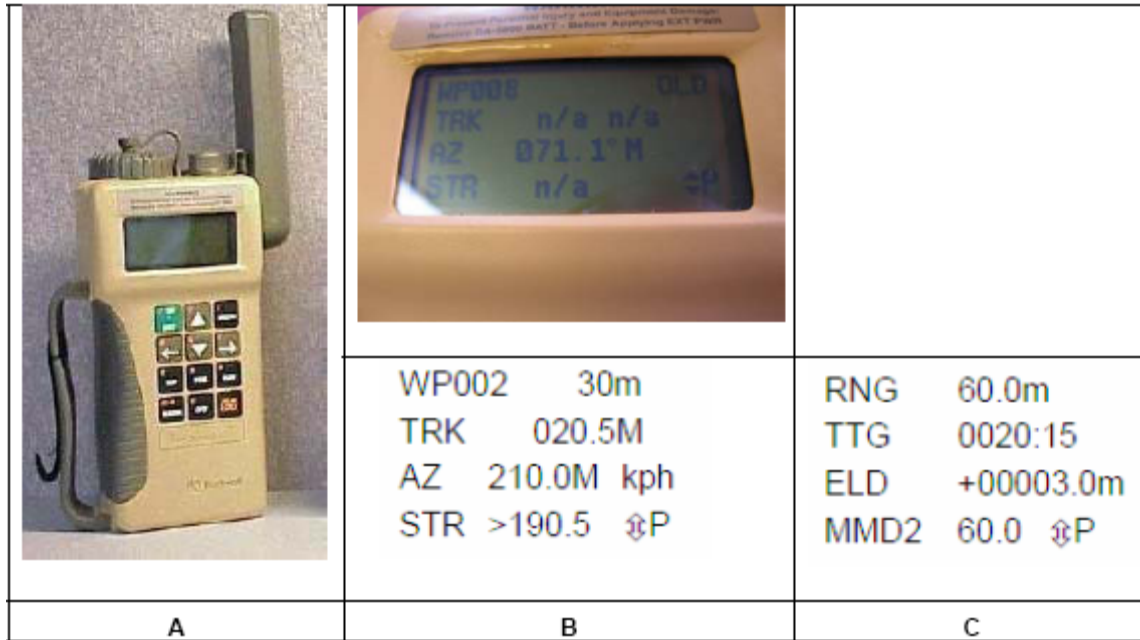
Figure 3. Army GPS precision lightweight GPS receiver (PLGR): device and two displays.

Table 1. Coding heading and distance on the tactile display.

	Vibrating location	**Vibrating rhythm**	**Sensation**
Distance > 50 m	Middle vibrator (for headings within a 45-degree forward cone)	200 ms on – 1800 ms off	Single click every 2 seconds
	Other vibrators (closest to the calculated heading)	200 ms on – 800 ms off	Single click every second
15 < Distance < 50 m	Middle vibrator (for headings within a 45-degree forward cone)	100 ms on – 200 ms off – 100 ms on – 600 ms off	1 double click per second
	Other vibrators (closest to the calculated heading)	100 ms on – 100 ms off – 100 ms on – 200 ms off	2 double clicks per second
Distance = 15 m	All	All on for 3 s	Long buzz

During each navigation course, Soldiers were requested to respond to radio communications, where they were asked questions regarding Army knowledge that they were expected to know, such as general orders, procedures, and features of armaments. Measures of performance included way-point completion (yes/no for each waypoint), time to reach waypoints, total time, mean deviation from the navigation route, and timeliness and accuracy of responses to radio requests. In addition, participants completed questionnaire-based assessments of each navigation device.

Results for this first experiment proved that the PTN can serve effectively for navigation and more effectively than the compass system. With the PTN, Soldiers reached 100% of waypoints, in comparison to 95% for PLGR and 86% for the compass system. Cochran Q test indicated that these differences were significant ($Q(2) = 9.33$, $p = 0.01$).

Soldiers navigated more quickly with the PTN or the PLGR compared with the compass system. Table 2 provides mean time to complete navigation course, mean response times to radio communications, and mean deviation from route. A repeated measures general linear model (GLM) analysis indicated that there were significant differences in mean course times among the three systems: $F_{(2,28)} = 28.2$, $p < .001$, $\eta^2_p = .67$. Table 3 provides paired comparison t-tests for the course times, which indicate the Soldiers were significantly slower with the compass than with the PLGR or the PTN. A repeated measures GLM of radio response times indicated that the differences among means were not significant ($F_{2, 28} = 1.37$, $p = 0.27$, $\eta^2_p = .09$). Although differences were not statistically significant, mean values were ordered as expected, with PTN having the shortest time. Differences among route deviation scores were significant (repeated measures GLM: $F_{(2,28)} = 17.6$, $p < .001$, $\eta^2_p = .56$). Follow-on comparisons indicate significant differences between the PTN and other systems but not between the compass and PLGR (see table 4).

Table 2. Summary statistics, course completion times, radio response times, and root mean squared error (RMSE; mean deviation from lane).

System	n	Course Times (Min:sec)		Response Times (sec)		RMSE (m)	
		Mean	SD*	Mean	SD	Mean	SD
Compass	15	36:48	5:21	9.13	4.22	13.3	12.0
PLGR	15	27:49	5:33	10.9	5.48	11.0	9.07
PTN	15	28:48	4:33	8.93	4.87	29.5	8.94

*SD = standard deviation

Table 3. Follow-on Holm's Bonferroni comparisons, mean total course times.

Comparison	df	t	Required p	Obtained p
Compass vs. PLGR	14	8.71	.017	< .001*
Compass vs. PTN	14	5.08	.025	< .001*
PLGR vs. PTN	14	0.78	.05	.448

*$p < .05$, two-tailed

Table 4. Holm's Bonferroni comparisons of RSME.

Comparison	df	t	required p	obtained p
PTN-Compass	14	5.31	0.025	< .001*
PTN-PLGR	14	5.59	0.0167	< .001*
Compass-PLGR	14	0.60	0.05	0.56

*$p < .05$, two-tailed

Soldiers deviated off course more when using the PTN than with other systems. Although this was unexpected, this result was clarified through discussion with the Soldiers. Soldiers indicated that the PTN made it easier for them to re-route around terrain obstacles, such as ditches and tall thickets, and still regain their direction to waypoint. This would explain why Soldiers deviated

more off course and yet still achieved their waypoints in less time than with the compass and just as quickly as when they used the PLGR.

Soldier evaluations of the PTN during this first experiment were quite positive. Soldiers rated characteristics on a 7-point numerical scale (1 = extremely difficult/ineffective to 7 – extremely easy/effective). Table 5 provides descriptive statistics.

Table 5. Mean ratings of PTN attributes.

Dimension	n	Mean	SD
Simple to learn	15	6.46	0.63
Simple to use	15	6.33	1.11
Can feel each tactor	15	6.26	0.70
Which tactor buzzed	15	6.40	0.73
Ease of following direction	15	6.26	0.79
Accuracy of guidance	15	5.80	1.20
Usefulness of guidance	15	6.13	0.83
Overall ease of use	15	6.46	0.74

In addition, 47% of the Soldiers ranked the PTN first in overall preference. Soldiers also indicated a high degree of operational relevance for missions such as night operations (6.64), military operations in urban terrain (MOUT) operations (5.64), reconnaissance (5.71), sustained operations (6.14), and operations in enemy territory (6.07).

Given the results for experiment 1, researchers planned a second experiment that would more highly tax the visual workload of Soldiers.

2.2   Night Operations

The second experiment with the PTN examined navigation performance by dismounted Soldiers in a multitask environment, with a main focus on target detection as well as navigating to waypoint. The effects of visual workload, mental workload, and degraded vision on land navigation performance were explored. To this end, the trials were performed at night; an off-limits area and an obstacle negotiation were added to the routes, and the Soldiers had to perform a target detection task. Three navigation systems were compared: the PTN (which requires little or no training and has a low cognitive, manual, and visual load), the standard Army PLGR which was used in experiment 1 (which requires training and practice, has a high cognitive and manual load, and a moderate visual load on the Soldier), and a helmet-mounted LW visual system (which requires moderate training, has a high visual load, and a moderate cognitive and manual load).

The LW system is a helmet-mounted, visually based Soldier information system. It provides the Soldier with a head-mounted visual display, on which different types of information can be presented (e.g., pictures of specific buildings or areas, information about unit position, etc.). For this experiment, the navigation information was used, and the display showed a map of the area on which the waypoints were indicated by icons and the Soldier's own position by a different icon.

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The display was presented to one eye (monocular); the night vision goggle was in front of the other eye. The Soldier always had the map with his own position in relation to the waypoints at his disposal (and thus knew where he had to go). Compared to the PLGR system, the LW system has a more intuitive display (map versus alphanumeric), thus lower cognitive load. Except for the Soldier having to adjust or move the monocular to or away from the eye, the system is hands free (moderate manual load). However, the visual load for the Soldier is high, especially when the night vision goggles also have to be used (see Duistermaat, 2005; Wainer et al., 2007).

Figure 4. LW helmet-mounted display (map-based visual overlay).

Since a tactile display has no visual load or low cognitive load, performance of the target detection task and local guidance SA was expected to be higher with the tactile navigation system than with the two visual systems. The PTN was coded similarly to that of experiment 1, with an additional change in cue pattern if the Soldier approached an off-limit area.

Terrain was wooded and rolling, with occasional ditches, gullies, and swampy areas because of extensive rain. The night conditions, along with the demand to search for targets, increased visual demands while decreasing visibility. The PTN was expected to be associated with higher perform-ance than the visual systems, while the LW system was expected to be easier to see and to interpret than the PLGR system. Eighteen Soldiers completed three navigation routes, each using a different navigation system. Each route was composed of three legs. During navigation on one leg, the Soldier was told to look for silhouette targets. In another leg, the Solder was told to look for live (human) targets. A third leg required the Soldier to move as quickly as possible. In the third leg, the Soldiers had to re-route around a large obstacle. Assignments of routes were counterbalanced with regard to order of task demands and navigation device.

Results from this second experiment showed that, in general, Soldiers navigated successfully, regardless of the device used. However, when significant differences were associated with performance, the PTN was associated with more effective performance.

The PTN was associated with faster navigation time while searching for silhouette targets and with finding more targets overall. Soldiers using the PTN system detected significantly more targets on the complete route (all lanes) than with the LW system. With the PTN system, Soldiers were significantly faster on the lane with three (live) targets than with the LW system. Table 6 provides means, standard deviations, p and effect size (partial eta squared, η^2_p) derived from repeated measures GLM.

Questionnaire-based evaluations from the Soldiers indicated that the Soldiers gave significantly higher evaluation ratings to the helmet-mounted LW map display and the PTN over that of the PLGR, for (a) staying on route, (b) being able to re-route around terrain obstacles, (c) avoiding off-limits areas, (d) finding waypoints, (e) maintaining SA, (f) accuracy of guidance, (g) effectiveness for daytime operations, (h), effectiveness for sustained operations, and (i) effectiveness for desert operations. Further, Soldiers gave significantly higher ratings for the PTN over both the PLGR and LW systems for (a) watching for terrain obstacles, (b) allowing hands-free operation, (c) ease of staying on route, (d) being simple to learn, (e) being simple to use, (f) effectiveness for night operations, (g) effectiveness for urban operations, (h) effectiveness for wooded terrain, and (i) effectiveness in enemy territory (see figures 5 and 6). In addition, Soldiers gave significantly higher ratings for the PTN over the PLGR (the LW was rated between the two), for watching for targets. The LW had highest ratings for being able to know one's location. This is because of the map display of the LW, which provides gridpoint location and an icon of the Soldier on the map (i.e., "you are here") relative to the PTN, which gave no location feedback except for cues indicating that one was getting close (i.e., 50 meters and 15 meters) to the waypoint. Table 7 provides descriptive results. Rating scales ranged from 1 (extremely ineffective/difficult) to 7 (extremely effective/easy). The results are based on data of 21 participants (incomplete data on three Soldiers because of weather conditions).

Table 6. Means and standard deviations for performance measures (N=18).

	PLGR		LW		PTN			
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**p**	η^2_p
Time (seconds)								
Navigation lane	626.27	274.57	659.89	193.54	636.44	199.14	0.89	0.00
Wide lane	897.05	226.60	791.94	175.55	775.00	165.93	0.13	0.11
Narrow lane	938.11	237.82	1013.72	283.74	852.67	289.40	0.01	0.23
Number of targets								
Silhouette	4.72	2.10	4.22	2.29	5.55	2.23	0.11	0.12
Live	1.67	1.32	1.55	1.25	1.83	1.15	0.80	0.01
All	8.77	2.83	7.78	3.06	9.95	2.79	0.06	0.15
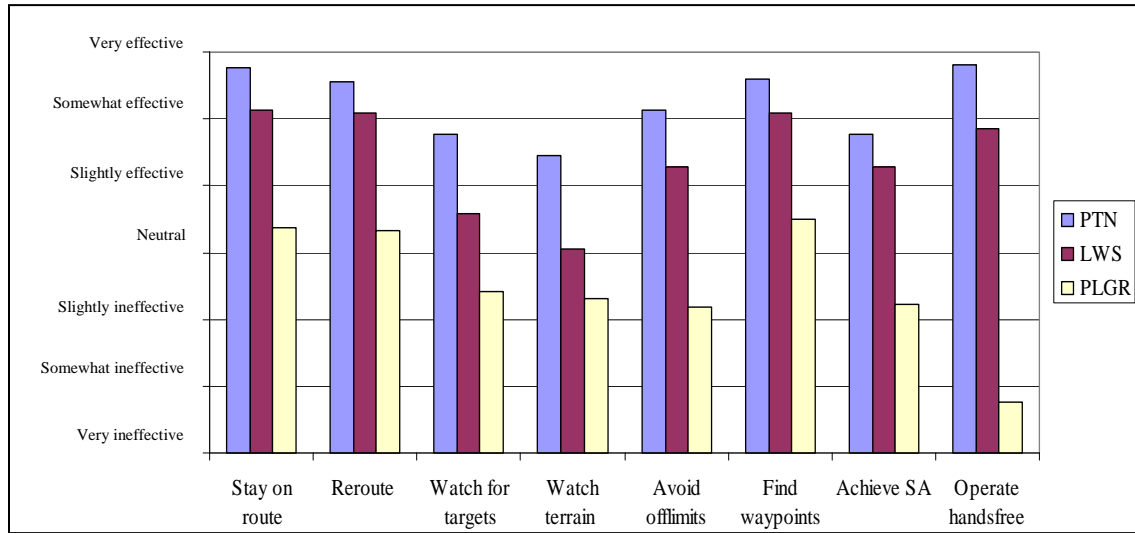
Figure 5. Mean questionnaire-based ratings for PTN, LW, and PLGR.
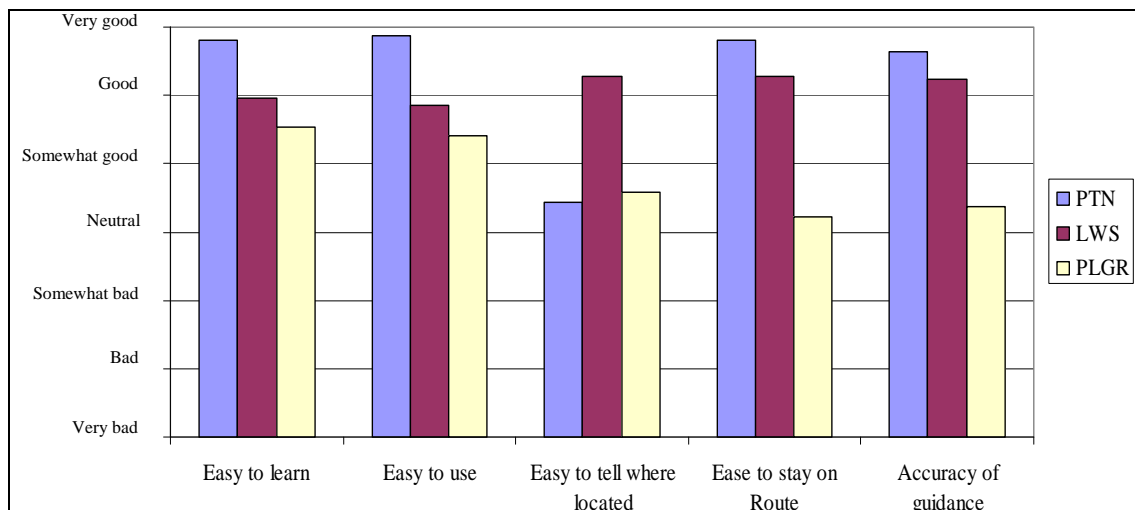
Figure 6. Mean questionnaire-based ratings for PTN, LW, and PLGR (N = 21).

The Soldiers rated the three systems in terms of their expected usefulness for several specific military operations (e.g., night operations, operations in urban territory), assuming that the system works perfectly, on a scale of 1 to 7 (very ineffective to very effective). Figure 5 depicts the differences in average rating before and after the Soldiers navigated with the systems.

A significant main effect was found for system type (F(2,40) = 25.7, $p < .001$), and a significant interaction effect (F(2,40) = 9.6, $p < .001$). *Post hoc* tests (Holm's Bonferroni: Holm, 1979) revealed that after the PTN system was used in the experiment, it was rated significantly more effective than before the experiment ($p < .05$). Also, the PLGR was rated significantly less effective than the PTN and LWS system, both before the experiment ($p < .01$) and after ($p < .001$). See figure 7.

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Table 7. Mean questionnaire-based ratings by device (N = 21; 7-point scale).

Evaluation Items	PLGR		LW		PTN	
	Mean	SD	Mean	SD	Mean	SD
Rerouting	4.28	1.73	6.05	1.24	6.52	1.03
Watching for Targets	3.52	1.80	4.67	2.05	5.75	1.55
Scanning Terrain	3.42	1.59	4.14	2.10	5.57	1.93
Avoiding Off-limits	3.09	1.30	5.29	1.55	6.09	1.13
Finding Waypoints	4.42	1.69	6.10	1.04	6.57	.81
Maintain SA	3.19	1.86	5.33	1.74	5.95	1.32
Performing Hands-free	1.80	1.20	5.95	1.35	6.80	.51
Simple to Learn	5.52	1.56	5.90	1.33	6.80	.40
Simple to Use	5.38	1.77	5.81	1.43	6.85	.35
Perceiving Display	5.52	1.56	6.19	1.50	6.00	1.73
Ascertain Location	4.57	1.93	6.29	.95	4.60	2.16
Staying on Route	4.14	1.82	6.29	.95	6.80	.40
Accuracy	4.33	2.03	6.24	1.33	6.61	.58
Usefulness for:						
Night Operations	4.09	2.32	5.95	1.53	6.80	.40
Day Operations	5.00	1.94	6.35	1.22	6.71	.71
MOUT Operations	3.04	1.85	5.24	1.60	6.28	1.00
Sustained Operations	4.23	2.04	5.81	1.28	6.28	1.00
Desert Operations	4.85	2.12	6.33	1.06	6.61	.74
Woods Operations	3.71	2.12	6.00	1.41	6.71	.64
Enemy Territory	3.90	2.25	5.57	1.88	6.57	.87
Land Warrior Attributes						
LW: Map (ease of reading)			6.67	.65		
LW: Map adjustments			5.67	1.35		
LW: Reliability			6.19	1.36		
LW: Night Vision			2.75	1.41		
LW: Nausea			1.55	1.14		
LW: Clutter			1.76	1.13		
PTN Attributes						
PT: Feeing Buzzes					6.82	.39
PT: Ascertaining Direction					6.91	.29
PT: Avoiding Off-limits					6.64	.79
PT: Using Mute button					6.05	1.32
PT_ Reliability of signal					4.10	.62

Conditions during this experiment (e.g., low visibility, swamp, mud, dense fog, light rain, etc.) impeded performance across all conditions and may have masked additional effects on perform-ance. That is, even if the Soldier could receive and interpret direction signals more easily, s/he may not have been able to travel faster because of conditions. Similarly, the dense fog affected night vision capability, and although this effect would be carried through all conditions, it may have also clouded differences in effects. That is, Soldiers who used the PTN and therefore had

more attentional visual resources to find targets, may have experienced such dense fog that they still would not see targets, regardless of their level of effort.
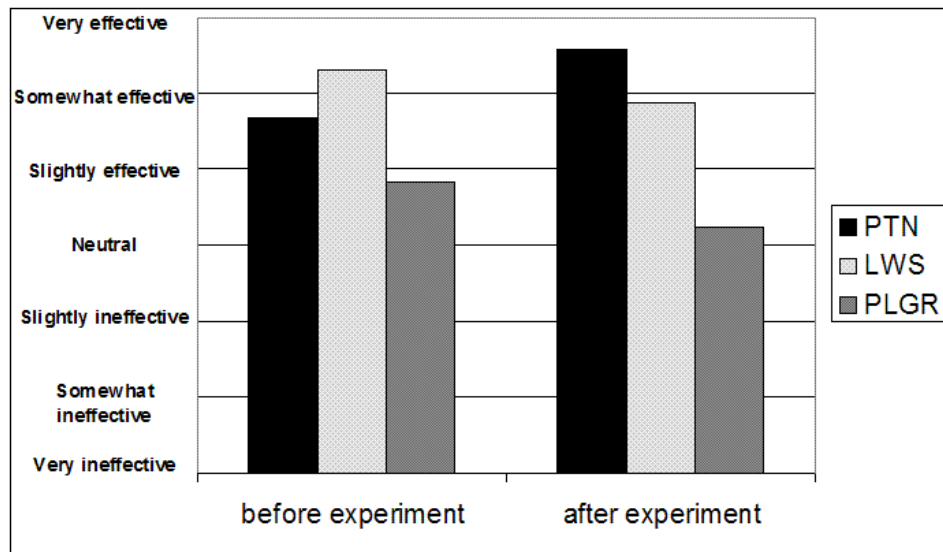
Figure 7. Pre- and post-ratings of each device for military usefulness.

The main conclusions from this study include

- Presenting navigation information on a tactile display decreases the visual load of the Soldier and seems to enhance the local guidance SA. This enables the Soldiers to use their eyes for other tasks, such as scanning the environment for landmarks and terrain characteristics and looking around for targets. As a result, the Soldiers detected more targets along the routes;

- The increase in detected targets did not influence the navigation speed of the Soldiers; with the tactile system the Soldiers navigated as fast, and on one lane even faster than with the visual systems, which also confirms the results of previous studies;

- The Soldiers rated the PTN system highly, especially for the hands-free and eyes-free aspects and the intuitive manner in which the information was presented. However, the Soldiers experienced difficulty in building a global SA when using the tactile display, because feedback about their position and distance to the waypoint was lacking.

This argues for an integration of a visual and a tactile display in a multi-modal navigation system, to combine the best aspects of both systems. This is expected to show further improved performance when Soldiers can use tactile information to navigate (hands-free, eyes-free, and with a low cognitive load) but are also able to check their visual display (at a self-chosen moment) to gain global SA.

Results from the two experiments showed high potential for tactile support of land navigation. This led to design of experiment three, which is detailed in this report.

3. Multimodal Land Navigation

The purpose of the third experiment was to extend investigation to questions regarding the effectiveness the PTN versus that of a more intuitive visual arrow display that also provides GPS-based location information. Here, the comparison was with a visual display that is more intuitive than other visual displays in previous comparisons. More particularly, researchers investigated the effectiveness of combined navigation systems where the Soldier would have access to both the hand-held visual arrow display and the PTN torso belt in order to identify which systems the Soldiers preferred to use, when, and why. Questions focused on the manner in which both systems were used when Soldiers had both devices. Questions regarded the relative effectiveness of each system for different performance criteria, such as navigation speed, target detection, and SA. This information is directly relevant to preliminary development of tactics and techniques associated with effective use when Soldiers have access to both systems.

3.1 Participants

Data were collected from 31 Soldiers from the Officer Candidate School (OCS) at Fort Benning, who voluntarily participated in the experiment. They ranked from E-4 (Specialist) to E-7 (Sergeant First Class), with more than half (19) being E-5. About one-third were relatively inexperienced (2 years or less), while the rest had several years of prior enlisted experience in various operational specialties. They averaged 5 years in the military (range = 1 to 16 years) and 1 year in the infantry (range = 0 to 6 years). The Soldiers ranged in age from 22 to 42 years (mean = 30 years). Although most reported previous experience and proficiency at daytime navigation (mean = 5.16 where 5 = "good"), they reported less familiarity with the regular Army GPS (mean = 2.30) and the commercial GPS (mean = 2.70, with 1 = no experience to 7 = expert). A rating of 2.7 is between "novice" and "OK". Soldiers did vary in their level of experience with the GPS from that of 1, "none," to that of 7, "expert". They had no previous experience with the PTN system.

3.2 Training

All Soldiers had previous experience in daytime navigation and reported high levels of proficiency (mean = 5.16, when 5 = "good and 6 = "very good"). Responses ranged from 3 "OK" to 7 "expert". They did not, however, all report high levels of proficiency with the Garmin (a commercial GPS device), and none had experience with the PTN.

An ARL representative reviewed principles of navigation and location determination when a map is used and trained the Soldiers in specific procedures with the Garmin. The Garmin was pre-programmed with waypoints and set on the "arrow" display, which also displayed grid point location information. Therefore, to use the Garmin, the Soldier needs only to look at the display and follow the direction of the arrow. A TNO representative trained the Soldiers to use the PTN system. After this, the Soldiers practiced and demonstrated proficient navigation to a waypoint in the field

with each type of navigation equipment. Because the PTN does not provide location information, Soldiers reviewed procedures of using a map to determine location in terms of military grid points. Soldiers evaluated training using a scale ranging from 1 "extremely ineffective" to 7 "extremely effective". They reported high levels of training effectiveness for the Garmin (mean = 5.89), the PTN (mean = 6.31), and map use (mean = 5.38).

3.3   Instruments and Apparatus

3.3.1 Personal Tactical Navigator (PTN)

The PTN is a custom-built device developed by TNO Human Factors (see figure 1). The same PTN device was used in all three experiments and is described in more detail here. The sensor pack consisted of a GPS sensor and an electronic compass. The sensor data were processed by the processing unit that compared the current position and heading with the stored route. The processing unit also stored the data and controlled the eight-element tactile display.

The tactile display consisted of eight vibrating elements (1.3 V vibrating DC motors, JinLong Industries, housed in rectangular hard plastic boxes) with a contact area of 1.5 by 2.0 cm and a vibration frequency of 155 Hz. The boxes were mounted in an adjustable waistband. The resolution of the displays (i.e., eight tactors for 360 degrees) is in between the minimum required (i.e., two elements: one for left and one for right) and the limit of direction perception on the torso (as shown by Van Erp, 2005, to be on the order of 10 degrees). The locations of the elements in the belt were adjustable so they could easily be positioned in the direction of the cardinal and oblique axes, regardless of the body form of the subject. The waistbelt was worn over the subject's underclothing.

The processing unit, sensors, and tactile display received their power from a rechargeable battery pack. The sensor pack, processing unit, and power supply had individual aluminium housings and options for integration with a backpack or battle dress uniform. To ensure a proper GPS receptance, the sensor pack should be worn on the upper part of the torso. The processing unit could be connected to a box that contained connections for keyboard, mouse, visual graphic array monitor, floppy drive, and ethernet and to a set of five control buttons that could be used to start and stop the equipment or to choose a route. The box and the control buttons were disconnected during the actual experiment.

The update rate of the GPS unit was 1 Hz; however, the system ran at 10 Hz or more. This means that the data from the digital compass could be used to signal a course deviation even without a GPS update on exact location. This enables the PTN to (a) detect course changes without changing location (e.g., when turning around one's axis) and (b) provide feedback during fast course changes.

Information about calculated waypoint heading and distance was provided as described in table 8. Heading was coded in the location of vibration. To indicate that the distance to the waypoint was less than 50 m, the sensation changed from a single to a double click (i.e., two bursts of vibration).

Furthermore, the middle vibrator had a lower rhythm than the other seven for the following two reasons: (a) to make it distinct from the others (as a redundant cue besides location), and (b) to lower the amount of tactile stimulation without losing confirmation that the system is working and the heading error is small. The values were based on several pilot studies. The PTN also changed signal rhythm when the Soldiers approach the off-limits area.

Table 8. Coding heading and distance on the tactile display.

Distance	Vibrating location	Vibrating rhythm	Sensation
> 50 meters	Forward tactor	200 ms on – 1800 ms off	Single click every 2 seconds
	Other tactors	200 ms on – 800 ms off	Single click every second
>15 < 50 meters	Forward tactor	100 ms on – 200 ms off – 100 ms on – 600 ms off	1 double click per second
	Other tactors	100 ms on – 100 ms off – 100 ms on – 200 ms off	2 double clicks per second
= 15 meters	All	All on for 3 s	Long buzz

3.3.2 Garmin GPS-Integrated FRS/GMRS Radio[2]

This is a pocket-sized hand-held combination GPS and radio (see figure 8) that has a color screen (256-color sunlight readable), automatic route generation, off-route recalculation, turn-by-turn directions with alert tones, and icon-driven menus. For this study, Soldiers did not need to learn how to use all functions. Instead, waypoints were pre-programmed for them so that they needed only to glance at the display to know the direction to walk. The display also showed the location in military grid points and the distance in meters to the next waypoint.

3.4   Land Navigation Course

The experimental route, located at Fort Benning, consisted of an 1800-meter triangular route, comprised of three legs of equivalent length (600 meters) as shown in figure 9, which shows the starting point, waypoints, and points where the Soldier was requested to provide location information. Six silhouette targets were distributed along the first half of each leg (see figure 4). Each target was labeled (e.g., A1-A6; B1-B6; C1-C6). The distance of the targets from the route was affected by terrain; targets were farther away if they could still be seen and closer if terrain was more heavily forested (see figure 10).

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[2]Family Radio Service/General Mobile Radio Service; http://www.garmin.com/ garmin/cms/site /us/ onthetrail/

Figure 8. Garmin hand-held GPS and arrow display.
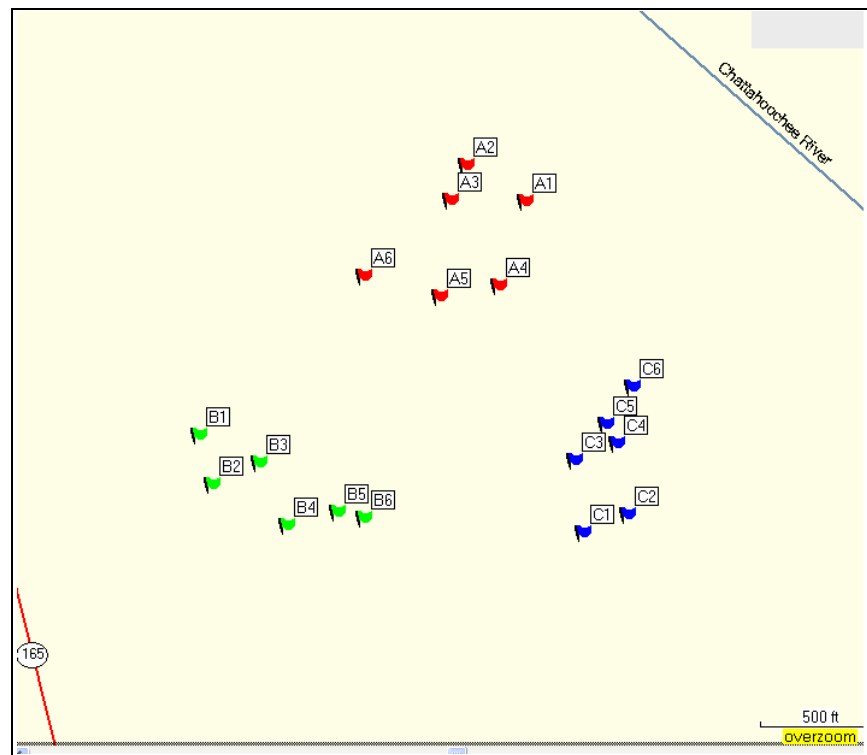
Figure 9. Navigation route with three legs.

3.5 Procedures and Experimental Design

Six or seven Soldiers participated each day, for 5 days. Each Soldier was trained on the PTN and Garmin navigation systems before data collection began. Soldiers demonstrated proficiency with each system at the end of training after practice with each system.

The study was a within-subjects design; that is, each Soldier navigated the 1800-meter land navigation route, using a different navigation system for each leg (the PTN, the Garmin, or both). The order of device assignment was counterbalanced to prevent confounds attributable to terrain differences among the legs.

For the first half of each leg, Soldiers were told to look for silhouette targets. Data collectors recorded which targets were identified and the distance, using a laser range finder, to each target when it was identified. Soldiers were then stopped by the data collector at pre-determined locations about halfway through each leg, after all targets were passed. They then provided grid location information using the Garmin or the map, while the data collector recorded location information and time taken to determine location.

For the second half of each leg, Soldiers were told they did not need to search for targets but to navigate to their waypoint as quickly as possible. After they were at their waypoint, data collectors recorded time and waypoint data. In addition to target and location information, data collectors recorded navigation time to each waypoint. These measures are discussed in more detail next. At the end of the navigation task, Soldiers provided a questionnaire-based assessment of each device. Questionnaires are described in further detail next.

3.6 Performance Measures

Performance measures were collected by data collectors who accompanied the Soldier on his route. During the navigation course, they observed and recorded the following.

3.6.1 Time to Complete Land Navigation Course Trials

After recording the starting time, data collectors followed each Soldier on his route. They used a stopwatch to record time to each waypoint, pausing the stopwatch during location assessment, and at each waypoint for data recording and GPS adjustments. Thus, the time recorded reflected only the time to travel.

3.6.2 Mean Deviation From the Navigation Route

Each data collector wore a commercial GPS (Garmin E-Trex Legend C). The system enabled tracking of the Soldier's route and comparison of the Soldier's route with the straight-line route. Deviations were not recorded unless they were more than 20 meters to the right or left of the centerline. In other words, the allowed course was 40 meters wide. The root mean square (rms) (square root of mean squared deviations) deviation was then calculated for each land navigation trial at 5-second intervals. Figure 10 shows the navigation route, the 40-meter corridor, and the

actual route walked by a particular Soldier. Waypoints are marked along the route every 30 meters. The distance of deviation from the corridor was assessed and recorded for each 30-meter mark (see figure 11). If the deviation was to the left of the actual route, it was recorded as a negative number; it was recorded as positive if the deviation was to the right. The mean deviation was calculated for each leg in order to determine amount and direction of deviation. Also, each deviation was squared in order to calculate mean square and rms for each leg, with the following formula:

The RMSE for a collection of N values $\{x_1, x_2, \ldots, x_N\}$ is

$$x_{\mathrm{rms}} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} x_i^2} = \sqrt{\frac{x_1^2 + x_2^2 + \cdots + x_N^2}{N}}$$

Figure 10. Part of the navigation route and a silhouette target.
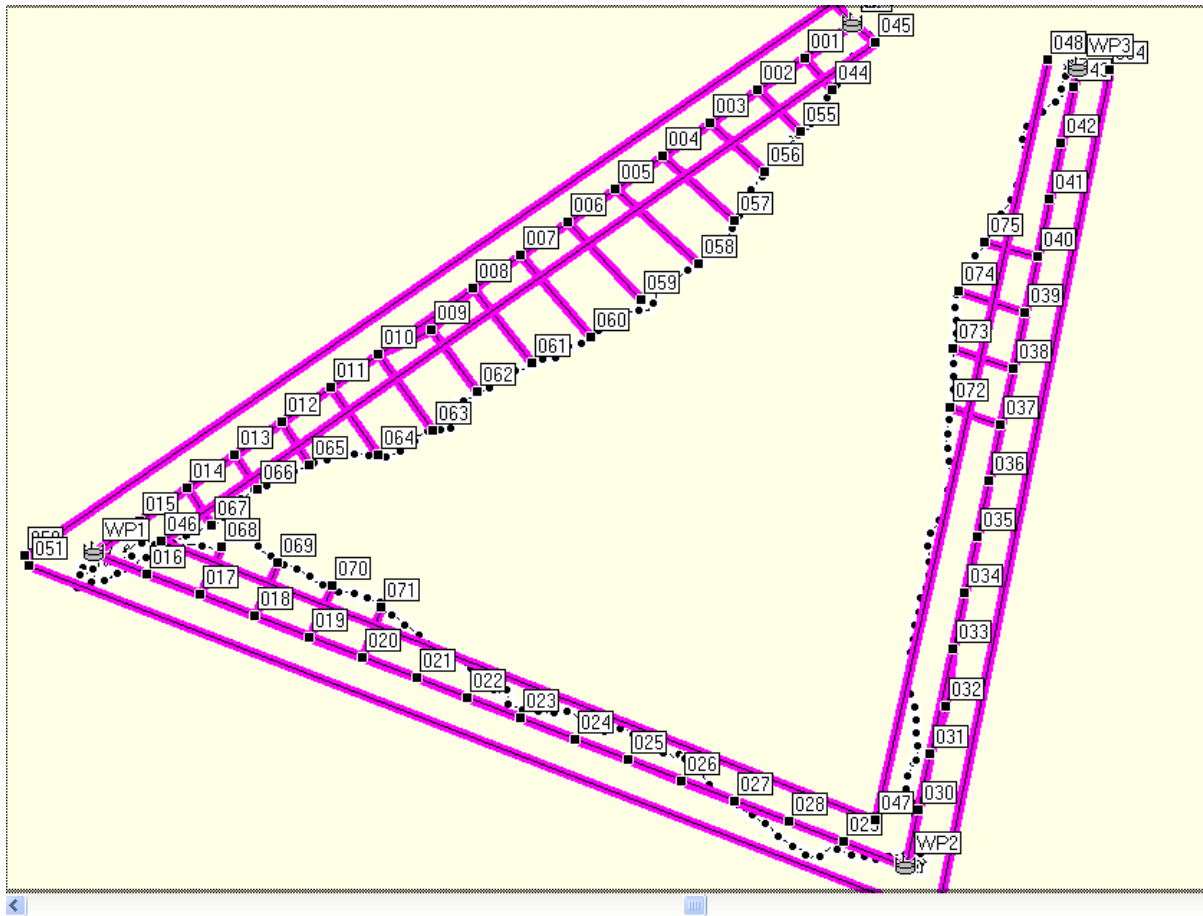
Figure 11. MapQuest portrayal of navigation route, with 20-meter corridor, actual route walked by Soldier, and manner in which route deviation information was collected. (The middle solid line is the ideal course, while outer lines mark the 20-meter corridor. Dotted lines indicate the course walked by the Soldier.)

3.6.3 Waypoint Completion

Data collectors noted whether Soldiers found each waypoint that represents the end of a leg (three waypoints). If a Soldier deviated too far from the waypoint (100 meters laterally or 50 meters beyond), s/he was stopped by the data collector and led to the waypoint. This was noted as failure to reach waypoint.

3.6.4 Number of Targets Detected and Distance Information

Using a laser range finder, data collectors noted which targets were detected along the route and recorded distance from each target identified by the Soldier.

3.6.5 Accuracy and Time of Location Estimation

Data collectors noted the actual grid point location, using their own GPS device, and the location estimated by the Soldier. They also noted the time taken to estimate location, based on a stopwatch.

3.7 Questionnaire-Based Measures

After Soldiers completed navigation routes with each system, they answered a questionnaire assessing various aspects of the PTN, the Garmin, and the use of both together. Soldiers rated aspects of each system on a 1- to 7-point scale, ranging from extremely ineffective to extremely effective. Soldiers were also asked to describe what they liked and disliked about each system and how they would use the systems in combination.

3.7.1 Rating Scale of Mental Effort (RSME)

Soldiers provided a global rating of mental effort to describe overall (mental) workload associated with navigation in each condition. The RSME has been used in various human factors evaluations, more commonly in Europe (de Waard, 2006; Brookhuis & de Waard, 1993). This global scale was collected in order to compare it with ratings of difficulty associated with the performance of specific tasks.

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4. Results

The following provides summary results from experiment 3. In addition, transcribed Soldier comments are shown in appendix A. Appendix B presents the workload rating scale, appendix C shows other questionnaires, and appendix D presents more detailed statistical analysis.

4.1 Waypoint Completion

Both navigation systems were very effective at guiding Soldiers to waypoints. All Soldiers reached all waypoints without any problems, in each condition.

4.2 Navigation Speed During Target Detection

Table 9 provides mean navigation time for the first half of each leg, when Soldiers were looking for the silhouette targets. These differences were not statistically significant ($F_{2, 60} = 0.59$; $p = 0.55$; $\eta^2_p = 0.02$).

Table 9. Mean time to navigate during target detection portion.

Device	Mean total Seconds	SD	N
PTN	304.9	63.85	31
Garmin	289.3	69.88	31
Both	291.4	69.58	31

Table 10 provides mean navigation time for the second half of each leg, when Soldiers were told they no longer needed to look for targets and to focus on moving quickly. Soldiers navigated more quickly with the Garmin and less quickly with the PTN. Repeated measures analyses indicate that

the difference among means is significant (F 2,60 = 3.14; $p = 0.05$; $\eta^2_p = 0.10$). *Post hoc* paired comparisons using Bonferroni correction criteria (Holm, 1979) show that Soldiers navigated more quickly with the Garmin than with the PTN (see table 11).

Table 10. Mean time to navigate during speeded portion.

Device	Mean	SD	N
PTN	268.45	92.68	31
Garmin	226.22	57.96	31
Both	252.35	81.26	31

Table 11. Paired comparison tests for navigation speed during speeded portion.

Device Pairs		t	df	*p*
Pair 1	PTN - Garmin	2.327	30	.027
Pair 2	Garmin - Both	-1.827	30	.078
Pair 3	PTN_- Both	0.880	30	.386

4.3 Target Detection

4.3.1 Number of Targets Detected

Table 12 shows the number of targets detected for each device. Differences were not statistically significant (F 2, 60 = 1.09; $p = 0.34$; $\eta^2_p = 0.04$). Differences in target detection counts were more a function of differences among Soldiers (F 1, 30 = 425.44, $p = 0.00$).

Table 12. Mean number of targets detected.

Device	Mean	SD	N
PTN	3.2	1.74	31
Garmin	3.7	1.54	31
Both	3.5	1.45	31

4.3.2 Distance From Soldier to Targets Detected

Table 13 shows the average distance from the Soldier to the targets detected, by device. The differences among these mean distances attributable to device were not significant (F 2, 60 = 0.019; $p = 0.98$; $\eta^2_p = 0.01$). Differences in target distance values were mainly a function of differences among Soldiers (F 1, 29 = 741.40; $p = 0.00$).

Table 13. Mean distance of targets detected.

Device	Mean	SD	N
PTN	40.5	20.62	30
Garmin	41.0	21.80	30
Both	39.7	22.26	30

4.4   Determination of Location With the Map Versus Garmin

There was no doubt that the Garmin would provide location information faster and more accurately. The Soldier needed only to glance at the display, and in fact, the grid point location that was read from the display was taken to be accurate. In contrast, average error in determining the grid point location with the use of the map was 178 meters (SD = 136.9). Measures of accuracy and time were recorded simply to ascertain the time and accuracy associated with using the map. Table 14 shows that it took an average of 2.5 minutes to determine location using a map, compared to an average of 7 seconds to check the Garmin display.

Table 14. Time to determine location by device (seconds).

Device	N	Minimum	Maximum	Mean	SD
Map	31	69.00	322.50	150.5	69.91
Garmin	31	2.00	23.00	7.2	3.84
Both	31	3.00	53.00	10.9	11.39

Table 15 provides the mean error in meters when Soldiers were required to estimate the distance to a previous or next waypoint. Soldiers estimated distance to waypoint twice with each device. Although errors are significantly larger using the map (F 2, 60 = 19.88; p = 0.00; see table 16 for *post hoc* comparisons), it may be that the errors are not that large from an operational perspective.

Table 15. Mean error (meters) in estimations of distance to waypoints.

Device	Mean	SD	N
Map	23.45	16.38	31
Garmin	8.48	4.78	31
Both	9.88	7.39	31

Table 16. Post-hoc paired comparisons regarding estimated distance to waypoints.

Device Pairs		t	df	p
Pair 1	Map - Garmin	4.735	30	.000
Pair 2	Garmin – Both	4.887	30	.000
Pair 3	Map-Both	-.820	30	.418

4.5   Navigation Route Analyses

Two indices compared the Soldier's route to the assigned route. One was a direct measure of deviation in meters from the 40-meter corridor that represents being on route. If the Soldier deviated to the left, the deviation was recorded as negative, and to the right as positive. This allows examination of whether deviations were primarily to the left or right. In addition, the rms was calculated for each device and for each leg. First, it was noted that deviations tended to occur more often on the left, and particularly on the first leg (F = 7.56; p = 0.002). *Post hoc* tests using

Holm's Bonferonni's criteria indicate that leg 1 was significantly higher in deviation score from leg 2 ($p = 0.01$) and 3 ($p = 0.000$). Leg 2 was not significantly different from leg 3 ($p = 0.279$).

Table 17 shows the mean deviation from the 40-meter corridor representing on-course navigation. All means are negative, indicating that more deviation from the route occurred to the left. This is consistent with self-reports from Soldiers and informal observation from data collectors. Repeated measures analyses indicate that differences are not significant (F 2,56 = 0.655, $p = 0.52$).

Table 17. Mean directional deviation from route.*

Device	Mean	SD	N
PTN	-14.03	25.74	29
Garmin	-11.30	16.48	29
Both	-17.9	24.22	29

**Represents mean distance in meters from the 40-meter corridor representing on route, where a deviation to the left is negative, while a deviation to the right is positive.

Table 18 provides the mean RMSE by device condition. RMSE is a better indicator of absolute deviation distance from route. Mean RMSE ranged from 16.24 meters (Garmin) to 26.87 meters (PTN), showing that Soldiers stayed on route to a fairly accurate and consistent degree. In fact, deviation distance was more a function of terrain attributes, in that all Soldiers deviated a greater extent (and consistently to the left) on one of the legs, which was more hilly than the others. Repeated measures analyses indicate that differences in RMSE by device condition were not significantly different (F, 2, 56 = 1.87; $p = 0.16$; $\eta^2_p = 0.06$).

Table 18. Mean RMSE by device.

Device	Mean	SD	N
PTN	26.78	21.40	29
Garmin	16.24	17.14	29
Both	24.63	24.36	29

4.6 Rating Scale of Mental Effort (RSME)

Table 19 provides mean ratings from the Rating Scale of Mental Effort, a global assessment of overall effort. The mean workload rating for the multimodal condition (both) was lower than that of either device used alone.

Table 19. Mean workload ratings (RSME) by device.

Device	Mean	SD	Lower CI*	Upper CI	N
Garmin	27.96	15.53	22.27	44.67	31
PTN	25.96	17.90	19.40	32.53	31
Both_	19.58	16.07	13.68	25.48	31

*CI = 95% confidence interval

Table 20 provides paired comparison 95% confidence intervals and t-tests. Confidence intervals indicate that workload with the Garmin alone is significantly higher than with both. This is also indicated by the t-test with *post hoc* Holm's Bonferonni correction $p = 0.01$). Soldiers reported some difficulty assigning ratings, since there was a confound with regard to use of the map when the PTN was used.

Table 20. Paired samples test for RSME comparisons.

Device Pairs		95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
		Lower	Upper			
Pair 1	Garmin - Both	2.02353	14.75066	2.692	30	.012
Pair 2	PTN - Both_	-2.46124	15.23543	1.474	30	.151
Pair 3	Garmin - PTN	-5.62856	9.62856	.535	30	.596

4.7 Soldier Evaluations

4.7.1 Self-Ratings of Performance

Table 21 provides mean self-ratings of performance in each device condition (rating scale ranged from 1 = extremely ineffective to 7 = extremely effective). The overall F-test was significant (F 2,60 = 3.67; $p = 0.03$; $\eta^2_p = 0.11$). *Post hoc* paired comparison tests indicate that self ratings of performance were higher when both systems were used, compared to only the Garmin (see table 22).

Table 21. Self-ratings of performance in each device condition.

Device	Mean	SD	N
Garmin	5.83	0.96	31
PTN	6.19	0.65	31
Both	6.38	1.05	31

Table 22. Paired comparisons regarding self-ratings of performance.

Device Pairs		t	df	p
Pair 1	Garmin - PTN	-1.648	30	.110
Pair 2	Garmin - Both	-3.070	30	.005
Pair 3	PTN - Both	-.881	30	.385

Soldiers provided ratings of task difficulty associated with each device condition. Table 23 provides assessments of difficulty based on a scale ranging from 1 = "extremely difficult" to 7 = "extremely easy".

4.7.2 Paired Comparison Tests

Variables listed that were associated with a significant overall F-test were then analyzed with paired t-tests, and Holm's Bonferonni criteria were used to determine which paired comparisons

were significant. Results are summarized in table 23, which indicates which variables were significantly easier than others. Paired comparison tests and more detailed descriptive statistics are presented in appendix D.

Table 23. Mean ratings of task difficulty by device condition. (Bold values indicate device condition(s) found to be significantly easier.)

Tasks	N	Garmin	PTN	Both	F	p	Paired comparison outcome
Staying on Route	31	5.70	6.09	6.22	2.75	0.07	
Watching for targets	31	4.38	**6.45**	5.93	35.53	0.00	P>B>G
Moving quickly	30	5.56	6.16	5.93	2.81	0.07	
Watching for small terrain obstacles	31	4.87	**6.45**	5.87	24.58	0.00	P>B>G
Rerouting around large terrain obstacles	31	5.19	**6.35**	**6.06**	17.83	0.00	P,B>G
Finding waypoints	31	5.93	6.16	**6.45**	4.17	0.02	B>G
Knowing terrain directly surround you	31	5.12	**6.00**	**5.97**	11.47	0.00	P,B>G
Knowing your location relative to landmarks	31	5.41	5.47	**5.90**	3.39	0.04	B>P,G
Knowing your distance to next waypoint	31	**6.64**	4.74	**6.68**	62.56	0.00	B,G>P
Allowing hands-free operation	31	3.97	**6.64**	5.22	45.45	0.00	P>B>G
Simple to learn	31	6.26	6.58	6.58	2.78	0.07	
Simple to use	31	6.03	6.41	**6.45**	3.10	0.05	B>G
Ease of seeing or feeling display	29	6.00	6.10	6.24	0.62	0.54	
Ease of interpreting display	30	5.97	6.20	6.33	1.64	0.20	
AVERAGE of Above	31	6.13	5.50	6.13	15.06	0.00	

4.7.3 Accuracy of Device Conditions

Soldiers provided ratings of accuracy for each device condition (1 = extremely inaccurate to 7 = extremely accurate). Table 24 provides mean ratings. The overall F-test was significant ($F_{2, 60}$ = 9.10, $p = 0.00$). Paired comparison using Holm's Bonferonni criteria show that having both systems was considered more accurate than having the Garmin by itself.

Table 24. Mean ratings of accuracy by device condition.

Device	N	Mean	SD
Garmin	30	5.77	0.77
PTN	30	6.07	0.63
Both	30	6.43	0.89

Table 25. Paired comparison tests of accuracy by device condition.

Device Pairs	t	df	p
Garmin-PTN	-1.140	29	.264
PTN-Both	-1.775	29	.086
Garmin-Both	-2.804	29	.009

4.7.4 Potential Effectiveness for Military Operations

Soldiers were requested to assume that the system works perfectly (easy, lightweight, hardened, etc.) and to indicate how effective each device condition would be for military operations (1 = extremely ineffective to 7 = extremely effective). Repeated measures GLM results were significant (F 2, 58 = 4.26; $p = 0.02$; $\eta^2_p = 0.13$). *Post hoc* paired comparisons using Holmes-Bonferonni criteria show that having both systems was rated significantly more effective than having only the Garmin (see table 27).

Table 26. Mean ratings of effectiveness for military operations by device condition.

Device	N	Mean	SD
Garmin	30	5.80	1.12
PTN	30	6.00	0.87
Both	30	6.33	1.29

Table 27. Paired comparison tests of effectiveness by device condition.

Device	t	df	*p*
Garmin-PTN	-1.140	29	.264
PTN-Both	-1.775	29	.086
Garmin-Both	-2.804	29	.009

4.8   Soldier Comments

First, Soldiers responded by describing what they liked best about the Garmin. Almost all Soldiers listed knowledge and accuracy of location and distance to waypoint, which was displayed at all times. Simplicity was also commonly cited, in that they need only to follow the visual arrow (see appendix A for listed comments). Various suggestions were made regarding improvements of the Garmin, such as (a) adding topographical features, (b) making it hands free, (c) making it more accurate than 10 to 15 meters away, (d) making the display easy to read and simple to navigate, (e) making the screen larger, (f) adding mounts to secure it to a uniform, weapon, or wrist, (g) providing navigation information standing still, and (h) improving the accuracy and "steadiness" of the compass arrow. The most common theme had to do with making the device hands free so they can hold their weapon in ready position.

Soldier comments regarding what they liked best about the PTN consistently regarded its hands-free operation. Comments emphasized how the hands-free aspect and ease of operation allowed them to travel quickly, free their hands for their weapon, and focus attention on target detection. They also mentioned how the PTN let them know if they are near (within 50 meters) of the waypoint. Suggestions for improvement were more varied, including (a) making it smaller and lighter, (b) removing the external antenna, (c) making it easier to take off the backpack, (d) stronger vibrations, (e) making the direction cues more stable when they are ducking (e.g., navigating under brush), (f) making it more comfortable, and (g) incorporating it with clothing.

The most common suggestion for improving the PTN was to integrate it with the Garmin. The PTN and Garmin were experienced as particularly complementary. When Soldiers were asked how they would use each device if they had both, there was a common theme. Although Soldiers varied somewhat in how and when they would use the PTN and Garmin, Soldiers cited use of PTN for travel and use of Garmin to confirm location. Twenty-six of 31 Soldiers commented that they would use the PTN the most, particularly for travel. Twenty-eight of 31 Soldiers commented that they would use the Garmin to determine location. Soldiers commented that the PTN is particularly useful in combat operations when the weapon needs to be held ready to fire and attention must be focused for enemy cues. Some more experienced Soldiers provided specific suggestions. One suggested using the Garmin to cover large and clear areas, then transition to PTN for closer distances and when enemy contact is expected. Another provided steps: 1. Plot your starting point and direction of travel destination on the map (check for impassable terrain). 2. Enter data into Garmin and PTN. 3. Begin operation-movement. Use PTN in hostile zone. 4. Check Garmin when necessary or at each waypoint to verify destination. 5. Use the map if Garmin and PTN fail.

5. Discussion

A bottom-line finding from this experiment is that Soldiers were able to navigate effectively, regardless of navigation device(s) used. All Soldiers reached all waypoints without any problems and within reasonable times. This finding was not unexpected; Soldiers were all at least somewhat experienced in land navigation, and the PTN and Garmin devices were both particularly easy to use. Both devices had waypoints pre-programmed so that information was easily obtained and the data collector ensured the device was turned on and working. The Soldier needs only glance at his visual display or attend to the tactile signals to receive information. The visual interface consisted of an arrow indicating direction. The tactile signal originates from a tactile torso belt where the "buzz" indicates direction. Therefore, both displays provided a recognition-based response where information processing demand was very low. Interface functions such as waypoint programming or display menu navigation were not evaluated in this study. The focus in this study was the manner in which each device was used in a multi-tasked and realistic operational context, particularly when both devices were available.

5.1 Soldier Movement

When Soldiers were told to search for targets, they moved at a very similar rate, regardless of device condition (mean range = 4.8 to 5.1 minutes). However, Soldiers navigated more quickly with the Garmin than with the PTN when directed to move as quickly as safely possible (mean Garmin = 3.8 minutes; mean PTN = 4.5 minutes). This was counter to expectations because the demand to look at a visual display for direction information was thought to slow the Soldier. However, the arrow display required little cognitive effort to process; a quick glance was sufficient

to keep the Soldier moving. Also, Soldiers reported that the torso belt was fairly tight and constrained strenuous movement such as running uphill. In addition, some Soldiers reported a loss of tactile signal during strenuous movement.

Soldiers recommended that the torso belt be more elasticized and that the tactile signal be stronger or that the signal strength be more programmable. Finally, there may be a "trust" or "familiarity" factor in that Soldiers reported feeling more "tentative" about the equipment and reported gaining a great deal of trust during the course of the experiment. Thus, while Soldiers navigated a bit more quickly during strenuous movement, they also moved quickly with the torso belt and identified means by which it could be improved. Movement occurred during optimal daytime conditions; movement with the tactile system was found to be faster when visual conditions are degraded (e.g., night operations, fog, rain, etc.).

5.2   Target Detection

Soldiers were effective in target detection, regardless of navigation device. They found about the same number of targets, regardless of navigation device(s) used (mean range = 3.2 to 3.7 targets) and detected the targets from similar distances (mean range = 39.7 to 41.0 meters). Although the tactile system had some advantage in that it was "eyes free," the advantage did not affect performance, probably because the visual display was very easy and needed only a glance under good visibility, so that the Soldier could still scan his or her territory effectively.

5.3   Location Determination

There was no doubt that the Garmin would provide location information faster and more accurately than a map. The Soldier need only glance at the display, and the display reading was taken to be accurate. In contrast, average error in determining the grid point location with the map was 178 meters. When Soldiers estimated the number of meters to a particular waypoint, they were slower and less accurate with the map (mean error = 23.4 meters versus 8.5 for the Garmin). Although the tactile belt can be useful in situations when the hands and mind are busy (e.g., combat) or visibility is poor, the Garmin display is vital for quick accurate assessment of location.

5.4   Navigation Route Analyses

Soldiers deviated off course equally, regardless of display. There was a tendency for all navigation devices to be associated with more deviations to the left than to the right. This may be attributable to the GPS-based nature of all equipment or to features (natural or manmade) peculiar to the terrain. Soldiers were much more likely to deviate to the left in the first leg, where terrain was hilly.

5.5   Workload Findings

Soldier ratings of workload (RSME) indicated that the multimodal condition was associated with significantly lower workload compared to having just the Garmin. Workload associated with the PTN alone was similar to that of the Garmin alone. However, there was likely some confounding

of the ratings for the PTN since some of the Soldiers tended to rate this system higher because of the difficulty in using the map for location determination. Soldiers expressed a high preference for having both systems.

Questionnaire-based items probed issues of workload more specifically. Fourteen items asked Soldiers to rate the degree of difficulty associated with performing specific tasks. The Garmin and having both systems were associated with significantly "easier" ratings for "knowing distance to next waypoint". The PTN was associated with "easier" ratings than the Garmin with regard to "watching for targets," "watching for small terrain obstacles," "rerouting around large terrain obstacles," "knowing the terrain directly surrounding you," and "allowing hands-free operation". Having both systems was associated with significantly "easier" ratings for "re-routing around large terrain obstacles," "finding waypoints," "knowing terrain directly surrounding you," "knowing your location relative to landmarks," "knowing your distance to next waypoint," and "simple to use". Overall, Soldiers rated most of the tasks as easier when both devices were used.

5.6 Multimodal Use

Most important are findings relevant to how systems can be used most effectively when Soldiers have both. Soldier comments emphasized the advantage to having both. Soldiers preferred the Garmin for knowledge of location and waypoint estimation. They also appreciated the simplicity of the visual arrow display. Various suggestions were made regarding improvements in the Garmin, such as (a) adding topographical features, (b) making it hands free, (c) making it more accurate than 10 to 15 meters, (d) making the display easy to read and simple to navigate, (e) making the screen larger, (f) adding mounts to secure it to uniform or weapon or wrist, (g) providing navigation information standing still, and (h) improving the accuracy and "steadi-ness" of the compass arrow. The most common theme had to do with making the device hands free so that Soldiers can hold their weapons in ready position.

Soldiers particularly valued the PTN for its hands-free operation. Comments emphasized how the hands-free aspect and ease of operation allowed them to travel quickly, free their hands for their weapon, and focus attention on target detection. They also mentioned how the PTN let them know if they are near (within 50 meters) of the waypoint. Suggestions for improvement were more varied, including (a) making it smaller and lighter, (b) removing the external antenna, (c) making it easier to take off the backpack, (d) stronger vibrations, (e) making the direction cues more stable when they were ducking (e.g., navigating under brush), (f) making it more comfortable, and (g) incorporating it with clothing.

The most common suggestion for improving the PTN was to integrate it with the Garmin. The PTN and Garmin were experienced as very complementary. When Soldiers were asked how they would use each device if they had both, there was a common theme. Although Soldiers varied somewhat in how and when they would use the PTN and Garmin, they cited use of PTN for travel and use of Garmin to confirm location. Twenty-six of 31 Soldiers commented that they would use the PTN the most, particularly for travel. Twenty-eight of 31 Soldiers commented that they would

use the Garmin to determine location. Soldiers commented that the PTN is particularly useful in combat operations when the weapon needs to be held ready to fire and attention must be focused for enemy cues.

We did not have the opportunity to combine the LW helmet-mounted map display with the PTN. However, it is likely that results from this study would generalize to that combination as well. Although the LW system is hands free, the visual map display demands more attention than does the PTN. Certainly, there are issues with regard to integrating the PTN with the LW system and issues with regard to making the PTN more battle hardened and user friendly with regard to programming waypoints. These issues should be further investigated.

Previous findings have established the effectiveness for PTN for dismounted Soldier land navigation, particularly during conditions of low visibility and high visual workload. The purpose of this study was to assess how Soldiers can most effectively use both systems together. Results demonstrate effectiveness and high Soldier appreciation of having both systems. This report contains Soldier recommendations for how both systems can be improved and how best to use both systems in operations.

6. References

Aretz, D.; Andre, T.; Self, B.; Brenaman, C. Effect of Tactile Feedback on Unmanned Aerial Vehicle Landings. *Proceedings of the Interservice/Industry Training, Simulation, and Education Conférence (I/ITSEC)*, Orlando FL, 2006.

Boles, D. B. Multiple Resources. In W. Karwowski (Ed.), International Encyclopedia of Ergonomics and Human Factors. Taylor & Francis, 271-275, 2001.

Brookhuis, K. A.; de Waard, D. The Use of Psychophysiology to Assess Driver Status. *Ergonomics* **1993**, *36*, 1099-1110.

Carlander, O.; Eriksson, L. Uni- and Bimodal Threat Cueing with Vibrotactile and 3d Audio Technologies in a Combat Vehicle. *Proceedings of the 2006 Human Factors and Ergonomics Society*, San Fransisco, CA, 2006.

Chiasson, J., McGrath, B., Rupert, A. *Enhanced Situation Awareness in Sea, Air, and Land Environments*; DTIC Technical Report; Naval Aerospace Medical Research Lab: Pensacola FL, 2003.

de Waard, D. Personal communication, University of Groningen: The Netherlands, 7 February 2006.

Dobbins, T.; Samways, S. The Use of Tactile Navigation Cues in High-Speed Craft Operations. *Proceedings of the RINA conference on high speed craft: technology and operation*, London: The Royal Institution of Naval Architects, pp 13-20, 2002.

Dobbins, T.; Samways, S. *The Use of Tactile Navigation Displays for the reduction of Disorientation in Maritime Environments*. Qintiq Ltd Hants (United Kingdom) Centre For Human Sciences, 2003.

Doll, T. Synthesis of Auditory Localization Cues for Cockpit Applications. *Proceedings of the Human Factors and Ergonomics Society 30th Annual Meeting*, pp 1172-1176, Santa Monica, CA, 1986.

Duistermaat, M. *Tactile Land Navigation in Night Operations*; No. ADA454334; Soesterberg, The Netherlands: TNO Human Factors, 2005.

Elliott, L. R.; Redden, E.; Pettitt, R.; Carstens, C.; van Erp, J.; Duistermaat, M. *Tactile Guidance for Land Navigation*; ARL-TR-3814; Army Research Laboratory: Aberdeen Proving Ground, 2006.

Groen, E.L.; Van Erp, J.; Box, J.E.; Van Veen, H.A.H.C. Tactile Countermeasure fo Spatial Disorientation, *Proceedings of the 75th AsMA Annual Scientific Meeting: Frontiers in Aerospace Medicine*, Anchorage, AL, 2004.

Holm, S. A Simple Sequentially Rejective Multiple Test Procedure. *Scandanavian Journal of Statistics* **1979**, *6*, 65-70.

Keller, J. Human performance Modeling for Discrete-Event Simulation: Workload. *Proceedings of the2002 Winter Simulation Conference*, E. Yucesan, C. Chen, J. Snowdon, & J. Charnes (Eds.), 2002.

McGrath, B. J.; Estrada, A.; Braithwaite, M. G.; Raj, A. K.; Rupert, A. H. *Tactile Situation Awareness System Flight Demonstration Final Report*; Rep. No. 2004-10, Pensacola, U.S.A.: Naval Aerospace Medical Research Laboratory, 2004.

Mitchell, D.; Samms, C.; Glumm, M.; Krausman, A.; Brelsford, M.; Garrett, L. *Improved Performance Research Integration Tool (IMPRINT) Model Analyses in Support of the Situational Understanding as an Enabler for Unit of Action Maneuver Team Soldiers Science and Technology Objective (STO) in support of Future Combat Systems (FCS)*; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, 2004.

Nelson, W.T.; Bolia, R.; McKinley, R.; Chelette, T.; Tripp, L.; Esken, R. Localization of Virtual Auditory Cues in a High +Gz Environment. *Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting,* pp 97-101, Santa Monica, CA, 1998.

Raj, A.; Kass, S.; Perry, J. Vibrotactile Displays for improving Spatial Awareness. *In Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, pp 181-184. Santa Monica, CA: Human Factors and Ergonomics Society, 2000.

Raj, A. K.; McGrath B. J.; Rochlis, J. L.; Newman, D. J.; Rupert, A. H. The Application of Tactile Cues to Enhance Situation Displays. *Proceedings for the Third Annual Symposium and Exhibition on Situational Awareness in the Tactical Air Environment*, 2-3, 77-84, 1998.

Rochlis, J. L.; Newman, D. J. A Tactile Display for International Space Station (ISS) Extravehicular Activity (EVA). *Aviation, Space, and Environmental Medicine* **2000**, *71* (6), 571-578.

Rupert., A. H. An Instrumentation Solution for Reducing Spatial Disorientation Mishaps. I*EEE Engineering in Medicine and Biology* **2000a**, *19*, 71-80.

Rupert, A. H. Tactile Situation Awareness System: Proprioceptive Prostheses for Sensory Deficiencies. *Aviation, Space, and Environmental Medicine* **2000b**, *71* (9), A92-A99.

Sarter, N. B. *Multimodal Information Presentation in Support of Human-Automation Communication and Coordination*; In E. Salas (Ed.) Advances in Human Performance and Cognitive Engineering Research, 13-36. New York: JAI Press, 2002.

Sarter, N. B. Human Technology Interface: Multimodal Communication in Support of Coordinative Functions in Human-Machine Teams. *Journal of Human Performance in Extreme Environments* **June 2001**, *5* (2), 50-54.

Sarter, N. B. The Need for Multisensory Feedback in Support of Effective Attention Allocation in Highly Dynamic Event-Driven Environments: The Case of Cockpit Automation. *International Journal of Aviation Psychology* **2000**, *10* (3), 231-245.

Van Erp, J.B.F. Presenting Directions with a Vibrotactile Torso Display. *Ergonomics* **In press**, 48.

Van Erp, J.B.F. Guidelines for the Use of Vibrotactile Displays in Human Computer Interaction. *Proceedings of Eurohaptics* 2002 (pp. 18-22). Eds. S.A. Wall, B. Riedel, Crossan, A. & McGee, M.R. Edinburgh:University of Edinburgh, 2002.

Van Erp, J.B.F. *Tactile Navigation Display*; In: S. Brewster, R. Murray-Smith (Eds.): Haptic Human-Computer Interaction. Lecture Notes in Computer Science, pp. 165-173. Springer Verlag, 2001.

Van Erp, J.B.F; Groen, E.L.; Bos, J.E.; Van Veen, H.A.H.C. A Tactile Cockpit Instrument Supports the Control of Self-Motion During Spatial Disorientation, *Human Factors* **2006**, *48*(2), 219-228.

Van Erp, J.B.F.; Spapé, M.M.A.; Van Veen, H.A.H.C. *Waypoint Navigation on Land with the TNO Personal Tactile Navigator (PeTaNa) [Waypoint navigatie op het land met de TNO Personal Tactile Navigator (PeTaNa)]*; Report nr. TM - 03 - A045; 24 Dec. 2003.

Van Erp, J.B.F.; Van Veen, H.A.H.C. A Multi-Purpose Tactile Vest for Astronauts in the International Space Station. *Proceedings of Eurohaptics* 2003. Dublin Ireland: Trinity College, pp. 405-408, 2003.

Van Erp, J.B.F.; Van Veen, H.A.H.C. Vibrotactile In-Vehicle Navigation System. *Transportation Research part F: Human Factors* **2004**, *7*, 247-256.

Van Erp, J.B.F.; Veltman, J. A.; Van Veen, H.A.H.C.; Oving, A. B. Tactile Torso Display as Countermeasure to Reduce Night Vision Goggles Induced Drift. In: Spatial Disorientation in Military Vehicles: Causes, Consequences and Cures. *RTO Meeting Proceedings* 86, pp. 49-1 - 49-8. Neuilly-sur-Seine Cedex, France: NATO RTO, 2003.

Van Erp, J. B., & Vogels, I. M. L. C. Vibrotactile Perception: A Literature Review; Technical Report No. TM-98-B011; Soesterberg, The Netherlands: TNO Human Factors, 1998.

Van Erp, J.B.F.; Werkhoven, P.W. Vibrotactile and Visual Asynchronies: Sensitivity and Consistency. *Perception* **2004**, *33*, 103 -111.

Van Veen, H.A.H.C.; Spapé, M.; Van Erp, J.B.F. Waypoint Navigation on Land: Different Ways of Coding Distance to the Next Waypoint. *Proceedings of Eurohaptics* 2004, pp 160-165. München, Germany: Technische Universität, 2004.

Wainer, K.; Adams, C.; Edwards, E.; Hall, M.; Natze, S.; Powell, K.; Wilder, L. *Land Warrior (LW)/MountedWarrior (MW) Doctrine,Organization, Training, Materiel,Leadership and Education, Personnel, and Facilities (DOTMLPF) Assessment*; Technical Report TRAC-W-TR-07-029; TRADOC Analysis Center-White Sands Missile Range, NM, 2007.

Wickens, C. D. Multiple Resources and Performance Prediction. *Theoretical Issues in Ergonomics Science* **2002**, *3* (2), 159-177.

Appendix A. Transcriptions of Soldier Comments

What did you like BEST about using the GARMIN?
Knowing the exact grid locations, using waypoint direction arrow, seeing routes.
Direction, Distance.
Size of equipment, relatively easy to use (KISS).
I liked it as a reference to my pace count and it was very accurate getting to my point.
The Garmin gives you your distance to the next target/waypoint.
One look location and distance.
Ability to view information necessary to navigate in real time.
Knowing distance to waypoint. The GPS and knowing the 10-pt grid location arrow direction to the waypoint.
The only thing you have to do is to follow the arrow.
The distance to next waypoint display. It allowed me to stay alert without the pace count.
It gives you exact grid points and distance.
Quick information and map display.
Its display had everything I needed to know.
Garmin gives grid coordinates, and distance to destination, couldn't be easier.
Provides grid coordinates and accurate distance to checkpoint.
Seems to be very accurate. Makes land navigation go faster.
I liked that the Garmin provided the distance and the grid coordinates.
The fact that you can get the distance.
Knowing your distance.
Being on route.
Its easy to use and displays a visual reference to follow.
I do not have to remember pace count or look at my compass.
Arrow, grid and distance to known point.
Accurate distance calculation.
It was easy to recognize location (grid point) and distance to next point.
There is no hands-on map work.
Easy-to-read display. I like the arrow showing you the way. I like that it updates distance to target.
All information was displayed on the device and took no effort.
Easily accessible grid location and distance to destination.
It gave exact grid digit coordinates of location and told you exactly where to go and meters to target.
Knowing the exact distance from my destination and the exact grid coordinate.

How would you IMPROVE the GARMIN?
None at this time.
Move toward the forerunner 301 but along the line of military use. Topographical features are needed.
None at this time.
I would make it hands-free. Holding the Garmin and my weapon was bothersome.
At times the distance to the target was off by 10 or 15 meters.
Make it hands-free, less dependent on motion.
Easy to read buttons and simple navigation screen, ability to set distance and azimuth.
Screen larger. Securing mounts to uniform body or weapon.
Nothing.
I would make it display the right direction to the next waypoint without requiring movement.
No improvements.
It was my 1st time using a handheld GPS. It would be nice if I could mount it on my wrist.
Some type of "hands-free" operation would be best. Its difficult to hold an M203 and Garmin at the same time.
Mount on weapon or hands-free. Indicator for off azimuth (not sure if it had a signaling device).
Not sure, think it works pretty well.
By making it not a handheld device.
Never dealt with Garmin, I would have to know the system in order to make recommendation.
Not sure, but needs to be more hands-free.
Make it where it does not need to be held (hand) while you are moving and all. Attach to weapon, perhaps.
A wristwatch type display with a center/chest-mounted compass / direction sensor (to allow hands-free operation).
This could replace the compass. It needs a device (laser) that can tell the operator mil/or degree to a target for artillery or air support.
Direction arrow is too sensitive. Find a way to make the device hands-free.
The directional arrow, especially when stationary. Its difficult to interpret the direction of travel.
It would help if it also showed AZ to target to double check with Map AZ. I found that it was very "touchy". Every time I put it in my pocket, the display changed.
Arrow orientation needs to be faster (more accurate).
Allows hands-free and at eye level.
N/A
If possible, making the arrow more stable in its direction. It switched almost constantly.

What did you like BEST about the PTN?
Navigating without using map or Garmin was very effective, able to locate more targets and survey area.
Hands and thought-free.
Vibration to keep you on course.
Ability to concentrate on pace count, terrain, and enemy.
The PTN let you know if you were close (within 50 meters) of the target.
Easy direction .
Ability to be aware of surroundings and navigate quickly.
Led me to my point. Didn't need to hold in my hands.
The vibration helps you with the direction.
The fact that it did not require the use of my hands, like the Garmin and compass.
You don't have to look down at a Garmin or compass. You just look at your surroundings & scan for targets.
Easy to scan for targets.
Hands-free.
Idiot-proof operation, ease of use, accurate.
Hands-free and ease of use.
Free use of hands i.e. not having to hold map, compass, all the time.
I didn't have to hold something in my hand. I could use my weapon without having to worry about whether I was going to drop the device in my hand. It was very simple to follow. I could also keep moving without having to stop to make sure I was on track.
Hands-free system.
Hands-free guidance, very useful!
Direction (the way you need to go). A little uncomfortable on body.
It frees your hands an doesn't require the operator to look down in order to navigate.
I like the hands-free aspect of the system. It allows me to move without using the compass and scan for targets. It placed me within 20m (or visual range) every time.
Hands-free.
I was able to focus on terrain and target location rather than navigation.
It allows you to travel on heading without having to go dead reckoning. It gives a good sense of direction.
Hands-free, easy to focus on other tasks.
Hands-free.
It quickly directed me.
Allows you to move instinctively, almost as if your comrade is pulling you in the right direction.
Hands-free operation.
Having my hands-free was great, also the buzzing was not so great as to disturb my train of thought.

How would you IMPROVE the PTN?
Condense backpack portion into a smaller unit
The external antenna that protrudes from the top of the ruck (sack) does not allow Soldier to up at aircraft effectively. If you were infantry, you will take your ruck off and leave it at times
make it more durable
Stronger vibrations. I was moving and sometimes had to stop to feel the vibration. It would also help when breaking through brush, branches would hit me in the face and the sensitivity of the vibration would decrease
I would try to see if there was a way to improve the PTN's effectiveness when navigating under brush. If I ducked to avoid a vine, the PTN would vibrate towards my back or my sides instead of my stomach
Needs to adjust to different body sizes easier
Incorporate into equipment or clothing, or have ability to integrate with GPS.
Adjust the strength of the pulse. Lighter weight on the back
The vibration needs to be stronger once the adrenalin starts flowing
I would make it much smaller, i.e. no backpack portion, just the belt
no improvements
Improve the compass dip error
Smaller, lightweight, integrate with Garmin
The packaging could be improved, and some way of giving a distance to destination would make it the ultimate land navigation tool
As is, it worked fine, but could incorporate a display for overall distance to checkpoint/grid coordinates
Eliminate rucksack
By somehow making it give distance and grid coordination
Not an expert, pretty good system
Add a system to inform user of distance, grid, etc.
As you increase your movement the vibration increases harder on your body
Provide distance information to the Soldier
I need to know more about it: How do you plot the target points? How hard is it to change waypoints during a mission? How many points can I store in the system? If there is an obstacle that is not passable will it automatically change my route around the obstacle and back on target? Can you send new points to my system from the base by radio or satellite? Can the enemy detect me with this system? (by electronic means).
Need to tell grid and distance
add a device that tracks distance
Greater difference between the single, double, and buzzing. When moving fast its easy to move past points.
Too tight around my chest. When running could not get my breath. Could not feel it when running.
Placement/constriction of movement and breathing.
Allow for an azimuth and distance to destination reading.
If it incorporates GPS aspects of Garmin (grid location and distance)
Perhaps adding a removable display that would show distance, direction, and location of the destination.

When you used GARMIN, PTN, & MAP altogether, which device did you use the most, and why? For Navigation?
Garmin at first until confidence was strengthened using PTN.
PTN, only because it was constantly reminding me of direction.
PTN.
PTN-- Got me there quick and with the ability to concentrate on other things my pace count was confirmed with the 50m double vibration from PTN.
I mostly used the PTN for navigating because I found that it was a little more effective than the Garmin in pointing me directly to my target.
PTN, because its faster.
PTN, because there was no question about which direction to go.
Garmin because it gave the distance to the waypoint.
PTN because the vibration takes you straight to the point.
PTN it was more intuitive in determining direction.
PTN. Its easy to just follow the directions of the PTN.
PTN because it was easier to scan for targets.
PTN.
PTN because the device kept you on track the whole time.
Both, I would sometimes look at the Garmin to confirm direction.
PTN
The PTN because I didn't have to stop. It allowed me to keep moving.
I used Garmin to navigate, in order to get distance as well.
PTN, no thinking and hands free.
PTN.
The PTN-- because it was much quicker.
PTN because it is the easiest and fastest method.
Garmin, PTN.
The PTN because I didn't have to keep looking down to determine direction.
PTN, it gives a sense of direction and an idea when you arrive at the point.
Garmin, Because it tells you distance and direction.
PTN.
PTN-->No Map--->Garmin slightly.
PTN because it allowed for hands free navigation and allowed for effective use of weapon.
I used the PTN alone, because it was so easy to move around through the terrain.

When you used GARMIN, PTN, & MAP altogether, which device did you use the most, and why? For reporting locations?
Garmin.
Garmin. I did not have to spend time on the map.
Garmin
Map and Garmin together- initially look at Garmin, but the numbers change while I stand there so I look to Map to confirm location by distance and terrain association.
The Garmin made knowledge of my grid and location extremely easy. Therefore, when using all three, I used it instead of the PTN for reporting my location because the Garmin was more effective.
Garmin, because its faster.
GPS- ability to read location.
Garmin gave the grid locations required and no pace count.

The Garmin, automatically shows you the location and the direction you are going.
The Garmin was by far the easiest because of the display.
Garmin. It gives you accurate data.
Garmin because it showed the exact information that was required.
Garmin.
The Garmin was best for reporting locations because it gives the answers such as grid cords and distance, along with distance.
Garmin, ease of use.
Garmin
The Garmin because it provided distance and grid points.
PTN because of being hands free.
Garmin, it does all the work.
Garmin/map.
The Garmin, because it quickly and accurately displayed the required information.
Garmin-because it gives exact 10 digit grid.
Garmin .
The Garmin because it gave a grid coordinate.
Garmin, its far easier to read the grid coordinates.
Garmin-Because its easy to read from the display screen.
Garmin.
Garmin.
Garmin because it was the easiest way to coordinate grid location.
I used the Garmin because it gave exact locations.

What advice would you give to a Soldier who was issued the GARMIN, PTN, and MAP (all together) systems, on how best to use them?
Use all systems as a package and use each one independently based on mission and terrain and use others as reference.
Use all 3 systems.
Put your Garmin in your pocket and trust your pace and the PTN. PTN will get you there so trust it and kill the enemy. If you second guess yourself pull your Garmin out.
The PTN is really effective in directing you to your target. Use the PTN to keep you on course, and use the Garmin to verify your distance to the target. Use the Garmin to also verify your grid coordinates.
If you're expecting enemy contact, put the Garmin away. Also keep your land-navigation skills sharp, and pay attention, just in case they break
Check the WP grid according to the map and GPS and use the PTN to navigate between points.
Practice using them for familiarization before taking them to comment.
Do not rely on one, learn how to use all three of the systems.
I would tell him to primarily use the Garmin and PTN and keep the map in case the other two systems fail.
Use your map first to orient yourself and plot your grid points. Then rely on your PTN for moving and use the Garmin for grid points, direction and distance.
Use the map to back up the system. Do not rely on the system only.
The Garmin should be your default device but.. The PTN is the best tool to use to stay on course and look for targets, and there is no replacement for a map when one needs to perform terrain analysis and related tasks.
Rely on the PTN to stay on course; use the Garmin to verify pace count, but put it away so you are able to fire your weapon.

Don't overcompensate for the PTN sensors and use Garmin mostly for grid and distance to locations.
Use Garmin for pace count, and grid location, and use PTN to guide you.
I would advise the Soldier to use the PTN for navigation because it allowed for quick movement and it was hands free. I would advise the Soldier to use the Garmin to get distance and grid points. I would use the map for backup distance and grids.
Use Garmin for navigation, but for searching and destroying, it is the PTN .
Use PTN for direction guidance and use Garmin periodically for distance and grid
PTN- good at night and day, you can see your targets more effectively; Garmin: you have to constantly look at the equipment and you lose visual on targets.
Use the Garmin to cover large and clear areas. The transition to the PTN for closer distances and when enemy contact is expected.
1. Plot your start point and direction of travel destination on map (check for impassable terrain). 2. Input data into Garmin and PTN. 3. Begin operation-movement. Use PTN while in hostile zone. 4. Check Garmin when necessary or at each waypoint to verify destination. 5. Use map if Garmin and PTN fail.
Follow the feel of the PTN, want to know distance, location, pull out the Garmin.
Use the PTN unless you absolutely need to determine your exact location between points.
Garmin-- use for distance to point and grid coordinates. PTN: use for movement and approximate arrival at point. Map-- use for terrain association, planning for reconnaissance.
Trust the PTN, it will get you there. Make sure you are moving to get the arrow on the Garmin to orientate.
Use Garmin for distance and location and PTN to direct you as you move and look for targets (the enemy).
Utilize Garmin and PTN together. Use Gamin only when you need exact location and PTN to navigate. Trust equipment when navigating, but still have map reading skills should both devices fail.
Rely on the PTN to navigate, but when needing to know exact locations use the Garmin. The map could be used if both were to fail.

Comments
PTN was a good system. Once trust in equipment was achieved, PTN was a very good method.
I felt that the front (navel) sensor was a little faint. Maybe over a period of time the sensors will have a numbing effect to me and I would disregard.
Targets were low on ground but then on trees. Enemy Soldiers don't hang on a tree. Also they were not clear and I did not have my glasses. I was excited about the product and getting to the first point rather than the enemy. On 2nd point I broke through a lot of brush. Those may also be reasons I did not confirm many targets on 1st and 2nd point.
I like these systems, but I don't want to use them, because if I become dependent on them and they break, I wont have a prayer in the field.
The Garmin I feel is a better system and would benefit Soldiers.
Very effective system with both the PTN and Garmin. Nobody should get lost and everyone should get a "go" on land navigation tests. System should be used in the army ASAP.
Could also be modified to give direction changes if needed (especially during noise discipline) .
The PTN is an effective tool, and is hands free compared to a compass. However, a compass seems like it would be harder to break than the PTN.
At one point, I went past the checkpoint and the PTN signaled to continue straight, the Garmin lost signal 1 time during the testing. The PTN was much more effective in engaging and locating targets.

PTN is very useful for a Soldier. The hands-free ability is unmatched. But, the Garmin is extremely useful for grid and distance. Using the two together require no thinking!
If Garmin was on weapon, would be very easy to use, rather than holding it and always looking down; PTN a little uncomfortable on the body and hard to feel when you are running because you are focusing on your terrain.
The PTN was quickly learned and easy to use. I was impressed by the accuracy of the PTN (or should I say the interface's ability to lead the Soldier to the target).
Integrate with BFT/FBCBII. (direction tracking). And SINCGARS PRC119F radio and add a direction finding system. Put it all together into a man pack. I cans see this system in one of every nine Soldiers or one per squad. The system works well if set up and turned on and given to operator. Needs an operator for the system - one who can trouble shoot problems on the move.
I think the PTN is a fantastic concept. My only improvement would be to add a small LCD screen to the belt that determines distance and location.
Great system, its like "feeling" a compass.
Using the PTN and Garmin together was overkill and one contradicted the other. Several times, the PTN was bussing on one side while the Garmin arrow was pointing at least 90 degrees in the opposite direction. The PTN was very uncomfortable. I would not wear it in battle.
Combine both elements.
PTN is great for navigating especially when holding a weapon or other equipment; but for grid location purposes and knowing exactly where you are at, it is ineffective.

Rating Scale Mental Effort

Please indicate, by marking the vertical axis below, how
much effort it took for you to complete the task you've just finished

```
150
140
130
120
110                  EXTREME EFFORT
100                  VERY GREAT EFFORT
90
80                   GREAT EFFORT
70                   CONSIDERABLE EFFORT
60
50                   RATHER MUCH EFFORT
40                   SOME EFFORT
30
20                   A LITTLE EFFORT
10                   ALMOST NO EFFORT
0                    ABSOLUTELY NO EFFORT
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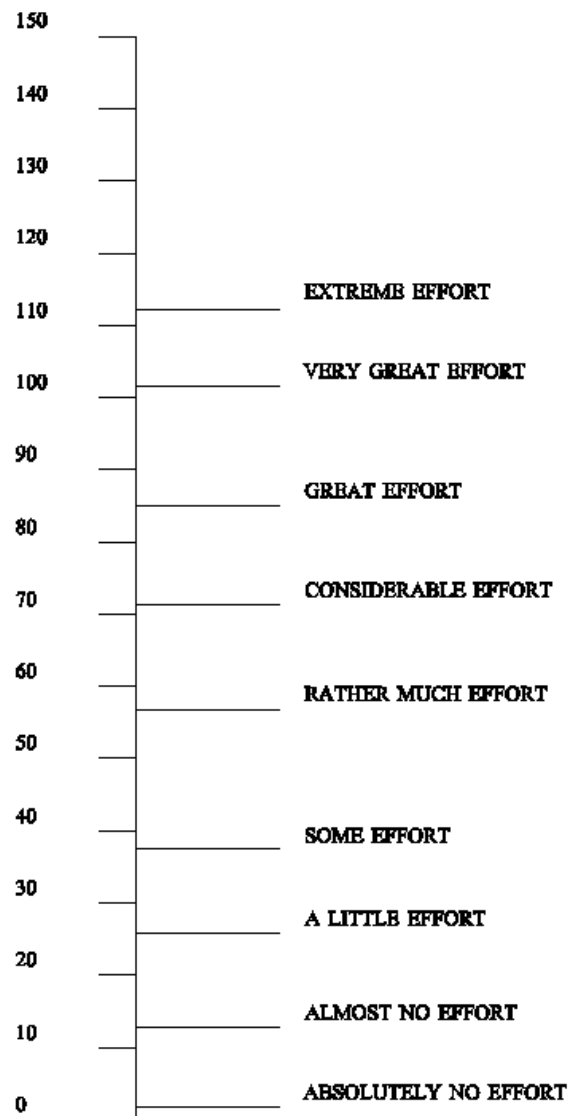
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Appendix C. Post-Experiment Questionnaire

Land Navigation: Visual and Tactile Cues

Roster Number _____   Date _____

You have now navigated three legs of a navigation course, using the
- GARMIN GPS system & Map
- PTN & MAP Tactile system & Map
- GARMIN GPS & PTN Tactile & Map

Please rate the training you had for each system:

Extremely Ineffective	Very Ineffective	Somewhat Ineffective	Neutral	Somewhat Effective	Very Effective	Extremely Effective
1	2	3	4	5	6	7

Quality of Training							
GARMIN	1	2	3	4	5	6	7
PTN	1	2	3	4	5	6	7
MAP	1	2	3	4	5	6	7

Please rate how well you navigated, using each system:

Extremely Ineffective	Very Ineffective	Somewhat Ineffective	Neutral	Somewhat Effective	Very Effective	Extremely Effective
1	2	3	4	5	6	7

YOUR performance using the:							
GARMIN	1	2	3	4	5	6	7
PTN	1	2	3	4	5	6	7
MAP	1	2	3	4	5	6	7
GARMIN & PTN & MAP (all together)	1	2	3	4	5	6	7

Please rate each, of the following items, with regard to **how easy** it was to perform the following tasks.

Extremely Difficult	Very Difficult	Somewhat Difficult	Neutral	Somewhat Easy	Very Easy	Extremely Easy
1	2	3	4	5	6	7

Staying on correct route							
GARMIN & MAP	1	2	3	4	5	6	7
PTN & MAP	1	2	3	4	5	6	7
GARMIN & PTN & MAP (ALL TOGETHER)	1	2	3	4	5	6	7
Watching for targets							
GARMIN & MAP	1	2	3	4	5	6	7
PTN & MAP	1	2	3	4	5	6	7
GARMIN & PTN & MAP (ALL TOGETHER)	1	2	3	4	5	6	7
Moving quickly							
GARMIN & MAP	1	2	3	4	5	6	7
PTN & MAP	1	2	3	4	5	6	7
GARMIN & PTN & MAP (ALL TOGETHER)	1	2	3	4	5	6	7
Watching for small terrain obstacles (holes, fallen logs, etc).							
GARMIN & MAP	1	2	3	4	5	6	7
PTN & MAP	1	2	3	4	5	6	7
GARMIN & PTN & MAP (ALL TOGETHER)	1	2	3	4	5	6	7
Rerouting around large terrain obstacles							
GARMIN & MAP	1	2	3	4	5	6	7
PTN & MAP	1	2	3	4	5	6	7
GARMIN & PTN & MAP (ALL TOGETHER)	1	2	3	4	5	6	7

Extremely Difficult	Very Difficult	Somewhat Difficult	Neutral	Somewhat Easy	Very Easy	Extremely Easy
1	2	3	4	5	6	7

Finding waypoints							
GARMIN & MAP	1	2	3	4	5	6	7
PTN & MAP	1	2	3	4	5	6	7
GARMIN & PTN & MAP (ALL TOGETHER)	1	2	3	4	5	6	7
Knowing details of terrain directly surrounding you							
GARMIN & MAP	1	2	3	4	5	6	7
PTN & MAP	1	2	3	4	5	6	7
GARMIN & PTN & MAP (ALL TOGETHER)	1	2	3	4	5	6	7
Knowing your location relative to landmarks							
GARMIN & MAP	1	2	3	4	5	6	7
PTN & MAP	1	2	3	4	5	6	7
GARMIN & PTN & MAP (ALL TOGETHER)	1	2	3	4	5	6	7
Knowing your distance to next waypoint							
GARMIN & MAP	1	2	3	4	5	6	7
PTN & MAP	1	2	3	4	5	6	7
GARMIN & PTN & MAP (ALL TOGETHER)	1	2	3	4	5	6	7
Allowing hands-free operation							
GARMIN & MAP	1	2	3	4	5	6	7
PTN & MAP	1	2	3	4	5	6	7
GARMIN & PTN & MAP (ALL TOGETHER)	1	2	3	4	5	6	7
Simple to learn							
GARMIN & MAP	1	2	3	4	5	6	7
PTN & MAP	1	2	3	4	5	6	7
GARMIN & PTN & MAP (ALL TOGETHER)	1	2	3	4	5	6	7
Simple to use							
GARMIN & MAP	1	2	3	4	5	6	7
PTN & MAP	1	2	3	4	5	6	7
GARMIN & PTN & MAP (ALL TOGETHER)	1	2	3	4	5	6	7

Extremely Difficult	Very Difficult	Somewhat Difficult	Neutral	Somewhat Easy	Very Easy	Extremely Easy
1	2	3	4	5	6	7

Ease of seeing (or feeling) the display							
GARMIN & MAP	1	2	3	4	5	6	7
PTN & MAP	1	2	3	4	5	6	7
GARMIN & PTN & MAP (ALL TOGETHER)	1	2	3	4	5	6	7
Ease of interpreting the display (knowing where to go)							
GARMIN & MAP	1	2	3	4	5	6	7
PTN & MAP	1	2	3	4	5	6	7
GARMIN & PTN & MAP (ALL TOGETHER)	1	2	3	4	5	6	7

Using the scale below, please rate the accuracy of each system

Extremely Inaccurate	Very Inaccurate	Somewhat Inaccurate	Neutral	Somewhat Accurate	Very Accurate	Extremely Accurate
1	2	3	4	5	6	7

Accuracy of the guidance toward the waypoint							
GARMIN & MAP	1	2	3	4	5	6	7
PTN & MAP	1	2	3	4	5	6	7
GARMIN & PTN & MAP (ALL TOGETHER)	1	2	3	4	5	6	7

Using the scale below, assume the system works <u>perfectly</u> (easy, lightweight, hardened, etc), how effective do you think they would it be for military operations:

Extremely Ineffective	Very Ineffective	Somewhat Ineffective	Neutral	Somewhat Effective	Very Effective	Extremely Effective
1	2	3	4	5	6	7

Military Operations: Effectiveness							
GARMIN & MAP	1	2	3	4	5	6	7
PTN & MAP	1	2	3	4	5	6	7
GARMIN & PTN & MAP (ALL TOGETHER)	1	2	3	4	5	6	7

What did you like BEST about using the GARMIN?

How would you IMPROVE the GARMIN?

What did you like BEST about the PTN?

How would you IMPROVE the PTN?

When you used GARMIN & PTN & MAP (ALL TOGETHER) , which device did you use the most, and why?

>   *For navigation* ?

>   *For reporting locations* ?

If one component of the GARMIN & PTN Navigation system were to fail during land navigation, which component would you rather have fail? Check one:

_____	I would rather have the GARMIN fail
_____	I would rather have the PTN fail
_____	No preference

What advice would you give to a Soldier that is issued GARMIN & PTN & MAP (all together)

systems, in how best to use them?

Comments:

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Appendix D. Descriptive and Paired Comparison Tests for Questionnaire-Based Ratings

	N	Min	Max	Mean	S.D.
RSME workload Garmin	31	4.00	76.00	27.96	15.535
RSME workload PTN	31	2.00	64.00	25.96	17.900
RSME workload Both	31	.00	72.00	19.58	16.074
Training effectiveness Garmin	31	4.00	7.00	5.87	.805
Training effectiveness PTN	31	5.00	7.00	6.25	.630
Training effectiveness Map	30	3.00	7.00	5.36	1.159
Performance Garmin	31	3.00	7.00	5.83	.969
Performance PTN	31	5.00	7.00	6.19	.654
Performance Both	31	2.00	7.00	6.38	1.054
Staying on route Garmin	31	4.00	7.00	5.70	.863
Staying on route PTN	31	5.00	7.00	6.09	.700
Staying on route Both	31	2.00	7.00	6.22	1.283
Identifying targets Garmin	31	2.00	6.00	4.38	1.282
Identifying targets PTN	31	4.00	7.00	6.45	.809
Identifying targets Both	31	1.00	7.00	5.93	1.340
Move quickly Garmin	30	3.00	7.00	5.56	.858
Move quickly PTN	31	2.00	7.00	6.16	1.067
Move quickly Both	31	2.00	7.00	5.93	1.289
Watching for small terrain obstacles Garmin	31	2.00	7.00	4.87	1.175
Watching for small terrain obstacles PTN	31	5.00	7.00	6.45	.675
Watching for small terrain obstacles Both	31	2.00	7.00	5.87	1.258
Rerouting around large obstacles Garmin	31	3.00	7.00	5.19	.980
Rerouting around large obstacles PTN	31	5.00	7.00	6.35	.754
Rerouting around large obstacles Both	30	4.00	7.00	6.06	.827
Finding waypoints Garmin	31	5.00	7.00	5.93	.727
Finding waypoints PTN	31	5.00	7.00	6.16	.637
Finding waypoints Both	31	3.00	7.00	6.45	.850
Awareness of terrain directly surrounding you Garmin	31	2.00	7.00	5.12	1.203
Awareness of terrain directly surrounding you PTN	31	4.00	7.00	6.00	.894
Awareness of terrain directly surrounding you Both	31	1.00	7.00	5.96	1.224
Knowing your location relative to landmarks Garmin	31	2.00	7.00	5.41	1.088
Knowing your location relative to landmarks PTN	30	3.00	7.00	5.46	1.136
Knowing your location relative to landmarks Both	30	2.00	7.00	5.90	1.093
Knowing your distance to next waypoint Garmin	31	5.00	7.00	6.64	.608
Knowing your distance to next waypoint PTN	31	3.00	7.00	4.74	1.031
Knowing your distance to next waypoint Both	31	5.00	7.00	6.67	.599
Allowing hands-free operation Garmin	31	1.00	6.00	3.96	1.425
Allowing hands-free operation PTN	31	5.00	7.00	6.64	.608
Allowing hands-free operation Both	31	1.00	7.00	5.22	1.726
Garmin_learn	31	5.00	7.00	6.25	.815

	N				
PTN_learn	31	5.00	7.00	6.58	.620
Both_learn	31	5.00	7.00	6.58	.564
Garmin_use	31	3.00	7.00	6.03	1.110
PTN_use	31	5.00	7.00	6.41	.71
Both_use	31	2.00	7.00	6.45	.99461
Garmin_perceive	29	4.00	7.00	6.00	.92582
PTN_perceive	30	4.00	7.00	6.10	.99481
Both_perceive	29	4.00	7.00	6.24	.87240
Garmin_interpret	30	3.00	7.00	5.96	1.03335
PTN_interpret	30	4.00	7.00	6.20	.84690
Both_interpret	30	3.00	7.00	6.33	.88409
Garmin_accurate	30	4.00	7.00	5.76	.77385
PTN_accurate	30	5.00	7.00	6.06	.63968
Both_accurate	30	3.00	7.00	6.43	.89763
Garmin_effective	30	1.00	7.00	5.80	1.12648
PTN_effective	30	3.00	7.00	6.00	.87099
Both_effective	30	1.00	7.00	6.33	1.29544
Garmin_fail	30	.00	1.00	.20	.40684
PTN_fail	30	.00	1.00	.70	.46609
no_fail	30	.00	1.00	.10	.30513
All_wkload_PTNTN	31	5.25	6.93	6.12	.42743
All_wkload_Garminarmin	31	4.07	6.36	5.50	.58085
All_wkload_Bothoth	31	3.07	7.00	6.12	.78604
Valid N (listwise)	24				

Paired comparison tests for Soldier ratings of difficulty

Detecting Targets	t	df	p
Garmin-PTN	-7.757	30	.000
PTN-Both	2.071	30	.047
Garmin-Both	-6.218	30	.000

Watching for small obstacles	t	df	p
Garmin-PTN	-6.848	30	.000
PTN-Both	2.683	30	.012
Garmin-Both	-4.229	30	.000

Rerouting around large obstacles	t	df	p
Garmin-PTN	-5.887	30	.000
PTN-Both	1.765	29	.088
Garmin-Both	-3.710	29	.001

Finding waypoints	t	df	p
Garmin-PTN	-1.366	30	.182
PTN-Both	-1.510	30	.142
Garmin-Both	-2.886	30	.007

Aware of surroundings	t	df	p
Garmin-PTN	-4.028	30	.000
PTN-Both	.166	30	.869
Garmin-Both	-4.034	30	.000

Knowing location relative to landmarks	t	df	p
Garmin-PTN	.150	29	.882
PTN-Both	-2.149	29	.040
Garmin-Both	-3.525	29	.001

Knowing distance to particular waypoint	t	df	p
Garmin-PTN	7.847	30	.000
PTN-Both	-8.358	30	.000
Garmin-Both	-.441	30	.662

Allowing handsfree operation	t	df	p
Garmin-PTN	-9.442	30	.000
PTN-Both	4.475	30	.000
Garmin-Both	-5.324	30	.000

Easy to use	t	df	p
Garmin-PTN	-1.836	30	.076
PTN-Both	-.215	30	.831
Garmin-Both	-2.145	30	.040

1   ARMY RSCH LABORATORY - HRED
        ATTN AMSRD ARL HR MQ M R FLETCHER
        US ARMY SBCCOM NATICK SOLDIER CTR
        AMSRD NSC WS E   BLDG 3 RM 343
        NATICK MA 01760-5020

1   ARMY RSCH LABORATORY-HRED
        ATTN AMSRD ARL HR MT J CHEN
        12423 RESEARCH PARKWAY
        ORLANDO FL 32826

1   ARMY RSCH LABORATORY-HRED
        ATTN AMSRD ARL HR MT C KORTENHAUS
        12350 RESEARCH PARKWAY
        ORLANDO FL 32826

1   ARMY RSCH LABORATORY - HRED
        ATTN AMSRD ARL HR MS C MANASCO
        SIGNAL TOWERS BLDG 29808A RM 303
        FORT GORDON GA 30905-5233

1   ARMY RSCH LABORATORY - HRED
        ATTN AMSRD ARL HR MU M SINGAPORE
        6501 E 11 MILE RD MAIL STOP 284
        BLDG 200A 2ND FL RM 2104
        WARREN MI 48397-5000

1   ARMY RSCH LABORATORY - HRED
        ATTN AMSRD ARL HR MF C HERNANDEZ
        2421 NW AUSTIN RD STE 220
        FORT SILL OK 73503-9042

5   ARMY RSCH LABORATORY - HRED
        ATTN AMSRD ARL HR MW L ELLIOTT
        BLDG 4 ROOM 332
        FT BENNING GA 31905-5400

1   ARMY RSCH LABORATORY - HRED
        ATTN AMSRD ARL HR MN R SPENCER
        DCSFDI HF
        HQ USASOC BLDG E2929
        FORT BRAGG NC 28310-5000

1   ARMY G1
        ATTN DAPE MR B KNAPP
        300 ARMY PENTAGON ROOM 2C489
        WASHINGTON DC 20310-0300

ABERDEEN PROVING GROUND

1   DIRECTOR
        US ARMY RSCH LABORATORY
        ATTN AMSRD ARL CI OK (TECH LIB)
        BLDG 4600

1   DIRECTOR
        US ARMY RSCH LABORATORY
        ATTN AMSRD ARL CI OK TP S FOPPIANO
        BLDG 459

1   DIRECTOR
        US ARMY RSCH LABORATORY
        ATTN AMSRD ARL HR MR   F PARAGALLO
        BLDG 459